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AN INEXPENSIVE AERIAL PENETROMETER

V. R. Marien, et al

Sandia Laboratories

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A research effort was conducted to establish the feasibility of and develop an inexpensive air-dropped penetrometer that can provide accurate measures of aircraft performance on unsurfaced airfields. This report describes the terradynamic, aerodynamic, structural, and telemetry system designs for the penetrometer and the results of field tests with a number of prototype units. Relationships are developed between the performance of the penetrometers and standard measures of trafficability. The feasibility of the use of a
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ABSTRACT (cont'd)

penetrometer system has been established. However, additional testing under field conditions is required to optimize the penetrometers operation before operational units can be produced.

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This technical report has been reviewed and is approved for publication.

Dennis L Brown

DENNIS L. BROWN
Capt, USAF
Project Officer

FOR THE COMMANDER

Frederick H Peterson

FREDERICK H. PETERSON
Asst Chief, Aerospace Facilities Branch

William B. Liddicoet

WILLIAM B. LIDDICOET
Colonel, USAF
Chief, Civil Engineering Research Division

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SECTION I

INTRODUCTION

The Air Force has been operating transport aircraft on soil runways since World War II with the aircraft ranging in size from the lightweight C-7 Caribou to the giant C-5A Galaxie. The missions have varied from resupply of troops to operational testing. The need for an accurate method to predict the takeoff distance, ground maneuverability, and landing distance on unpaved airfields has increased with the sophistication and cost of transport aircraft.

As part of the work to develop better ways to predict the performance of aircraft on soil airfields, a program was started in the early 1960s to develop a low-cost air-dropped penetrometer (ref. 1). In concept, a series of these penetrometers could be dropped onto a prospective landing site and soil strength data telemetered to the aircraft. These data would be translated into aircraft landing, ground, and takeoff performance by the aircraft crew for a decision on whether or not to land. Since the penetrometers would be small and quite cheap (i.e., $25 each), little penalty would be paid to provide this direct information to the pilot. This method also would preclude reliance on semitrained ground personnel or on a visual inspection for a decision to land. While of little use in operational test missions, the air-dropped penetrometers were considered to be a significant improvement in operational capability at remote airfields where environmental changes could rapidly degrade or improve an airfield or where skilled personnel were not available to evaluate airfield conditions.

From a technical standpoint, a method to measure both the static and dynamic response properties of a soil airfield is desirable. The idea of obtaining dynamic soil response data, which ties so closely with aircraft performance, prompted the work on an air-dropped penetrometer. Current techniques for making soil trafficability measurements use the penetration resistance of a cone slowly forced into the soil. This type of measurement provides static response data on the soil. An air-dropped penetrometer because of its impact and deceleration as it penetrates the soil, collects this range of dynamic response data. An aircraft depends on the dynamic response of the soil for support as it lands, taxis, and takes off but depends on the soils static response when parked. Most

aircraft operations are controlled by the dynamic response of the soil to loading. Poor static response can cause problems when aircraft are parked or stop rolling, but these problems can generally be remedied by covering parking areas with aluminum landing mat or other types of surfacings.

Over the years a large number of different types of penetrometers have been developed for measuring soil properties or for other purposes. The most successful organization in the development and testing of soil and rock penetrators is Sandia Laboratories (ref. 2). They have developed and tested penetrometers to measure the properties of a wide variety of materials, ranging from sea ice to concrete and soil. The basis for their design is the use of a carefully shaped and weighted device with one or more accelerometers and a reliable telemetry system. When the penetrometer is air dropped, the device penetrates the target material, the accelerometer senses the amount of deceleration, and this data is transmitted to an airborne or ground receiving station. The data are computer transformed into a depth versus deceleration plot for interpretation by a trained professional. Sandia Laboratories has had much success in applying its technology. However, all their penetrometers are expensive with most of this expense created by the use of accelerometers costing $100 to $400 each.

Since one of the objectives of this effort was to develop a low-cost penetrometer (i.e., $25 each in lots of 10,000), alternatives to the use of accelerometers were sought. Air Force Cambridge Research Laboratories (AFCRL) completed tests in 1969 on an enexpensive type of penetrometer (ref. 3). This design formed the basis for this effort.

The overall objective was to determine the feasibility of using a low-cost air-droppable penetometer to provide an aircraft commander with sufficient information to establish aircraft ground performance on any unpaved airfield.

SECTION II

PENETROMETER DESIGN

1. DESIGN PRINCIPLE

The penetrometer design is based on the principle that for a given impact velocity the depth of penetration of an object in soil is proportional to its weight and inversely proportional to its cross-sectional area. The current penetrometer design in its simplest form consists of a plastic finned aerodynamic case housing a pointed steel cylindrical rod (figure 1). After release from an aircraft it impacts the soil in a near vertical position. The case, being relatively large in cross-section area and lightweight, remains near the surface. The rod, being small in area and heavy by comparison, penetrates deeper into the ground (figure 2). This differential penetration provides an indication of soil strength which can be telemetered to airborne aircraft. This information is used to predict the surface suitability for landing.

2. BACKGROUND

Early penetrometers of this type were constructed of cardboard and styrofoam (figure 3), with the steel center rod housed in a fiberglass cylinder. After impact the rod separated from the case, cutting a series of wires connected to a resistor string. Each time a wire was cut the voltage in the circuit would be increased. These data were transmitted to a ground or airborne receiving station and a plot of separation distance versus time prepared. The soil strength was interpreted from this plot. The most severe shortcoming of this penetrometer was the fact that it was aerodynamically unstable. Other problems were: the telemetry system was not very reliable as the unit tended to overturn upon impact, the units could be used only once, and there was no correlation between separation distance or rate of separation and the performance of an aircraft on soil surfaces.

Perceiving these shortcomings, work was begun to: (a) develop an aerodynamically and terradynamically stable shape for a penetrometer; (b) test and select the best weight and shape configurations to provide consistent performance on soil; (c) establish general relationships between penetrometer and aircraft performance; and (d) develop a reliable sensor and telemetry system to measure

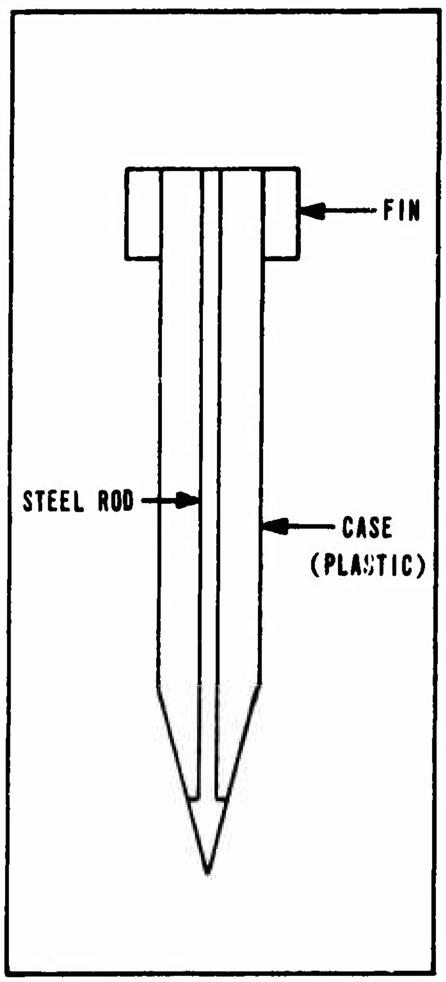

Figure 1. Penetrometer in Flight

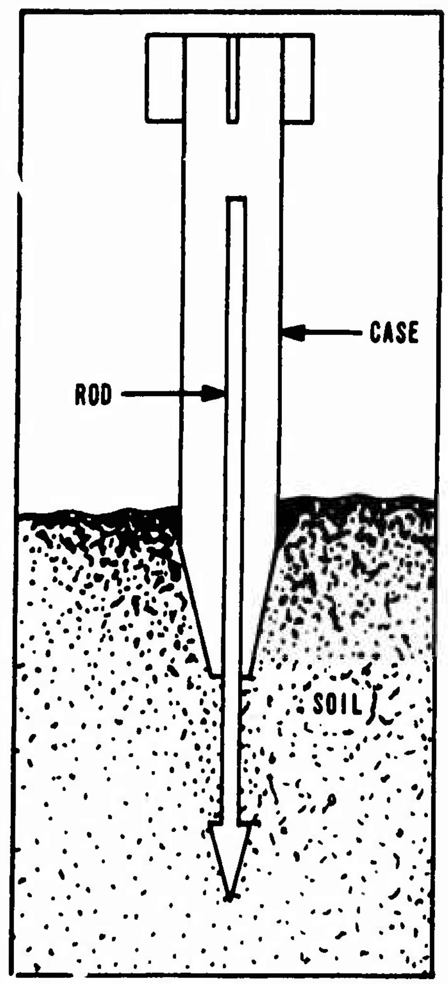

Figure 2. Implanted Penetrometer

NOTE: A low-cost, aerial, trafficability penetrometer.

Figure 3. Atlantic Research Penetrometer

the rate and amount of rod separation from the case. After this work was completed, an evaluation of the system would be conducted and plans made to develop engineering test penetrometers and develop quantitative relationships between aircraft performance and penetrometer data.

Early in the program, plans were made to relate rod separation distances with standard methods of measuring soil trafficability such as the California bearing ratio (CBR) and the airfield index (AI). The AI is obtained with the airfield cone penetrometer (ACP). (ACP and AI are used interchangeably in this report.) The ACP has a 0.5-in^2 (3.23 cm^2) cone with a 30-degree taper, and its resistance to penetration is measured with a calibrated spring in pounds. The airfield index divided by 10 and CBR are roughly equivalent for fine-grained soils. The dynamic cone penetrometer (DCP) was also used as a standard to measure soil strength, based on work by Young (ref. 2). The DCP is similar in shape to the ACP, having a 30-degree cone tip and a larger (0.75 in.^{2}, 4.84 cm^2) cross-sectional area. Dynamic cone Penetrometer readings were obtained by counting the number of blows from a 10-pound weight falling 12 inches, driving the tip 6 inches into the soil. By using both the ACP and DCP, standard measures of static and dynamic soil response were obtained during testing.

Nearly all natural soil landing sites tested, involving aircraft ranging in size from the C-123 to the giant C-5A transports, have been composed of fine sand or a fine-grained soil. Most of these landing tests were conducted on dry lake beds in California and Nevada which are composed of silt (ML) and clay soils (CL and CH). California bearing ratio and AI measurements used for the soil trafficability evaluations during these tests form the basis for the correlation of penetrometer data to aircraft performance until sufficient dynamic response data can be collected with the DCP.

Two design and test series were conducted. The first series optimized the terradynamic, aerodynamic, and mechanical design features and provided general correlation of penetrometer performance with the ACP and the DCP. During the second design and test series, minor weight and mechanical changes were made to accomodate a reliable telemetry system. The sensor and telemetry system were designed, tested, and evaluated during this series.

3. PENETROMETER DESIGN

Terradynamic aspects of the penetrometer design were considered the most important and received first attention. Aerodynamic, mechanical, and structural aspects of the design were considered secondary because they are better understood. Each aspect of the problem was viewed with the objective that a final design must be produceable in large quantities at less than $25.00 per unit and must provide data to a maximum depth of 30 inches for soils varying in CBR from 4 to 36.

The terradynamic design of the case and rod was based on the peformance of small diameter penetrators (ref. 2). The case was designed for consistent performance in soils and to be lightweight.

Only two nose shapes were fabricated. Configuration A had a length-to-diameter ratio (L/D) of 2.0 to 1.0 and configuration B a length-to-diameter ratio of 1.5 to 1.0 (figures 4 and 5). The rod weight was varied by inserting lead into the rod in an attempt to obtain higher impact velocities and more consistent results for a given soil strength.

Materials for the penetrometer were chosen based on cost and structural properties. The plastic case was a proven design borrowed from the BDU-17/B practice bomb. The nose adapter was machined from nylon because the fabric has an ability to withstand high-impact loads and mitigate impact shock. The rod was machined from steel with teflon rod guides to reduce friction. Other minor parts and pieces were made from plexiglass.

The case was designed to provide (1) a stable reference for measuring the movement of the penetrating rod, (2) aerodynamic stability, (3) support and protection for telemetry components, (4) penetration of not more than 12 inches (30.48 cm) in soils of CBR 4, and (5) economy in large quantities. The selection of a unit ballistic coefficient (aerodynamic drag-weight relationship, W/CDA) was made to minimize the influence of prevailing surface winds on impact and to avoid high-impact velocities. An average impact velocity of approximately 220 fps (67.06 mps) was selected for the penetrometer design.

The rod length-to-diameter ration (L/D) was important from a structural standpoint because very little bending and no permanent rod deformation could be tolerated. Based on an anticipated case penetration in soft soils of 12 inches (30.48 cm), a rod length of 20 inches (50.8 cm) was selected to cover

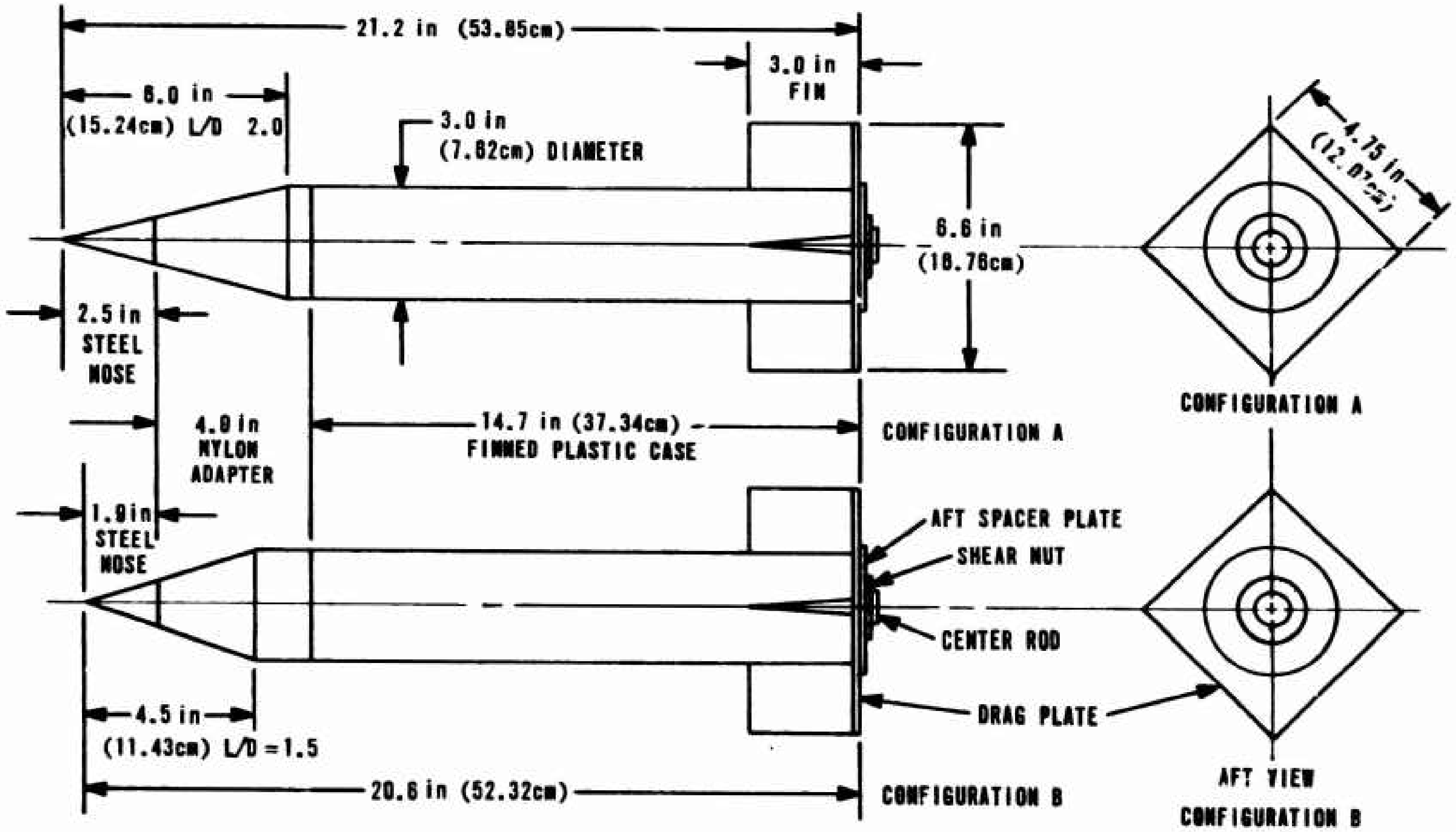

Figure 4. Basic Penetrometer Designs

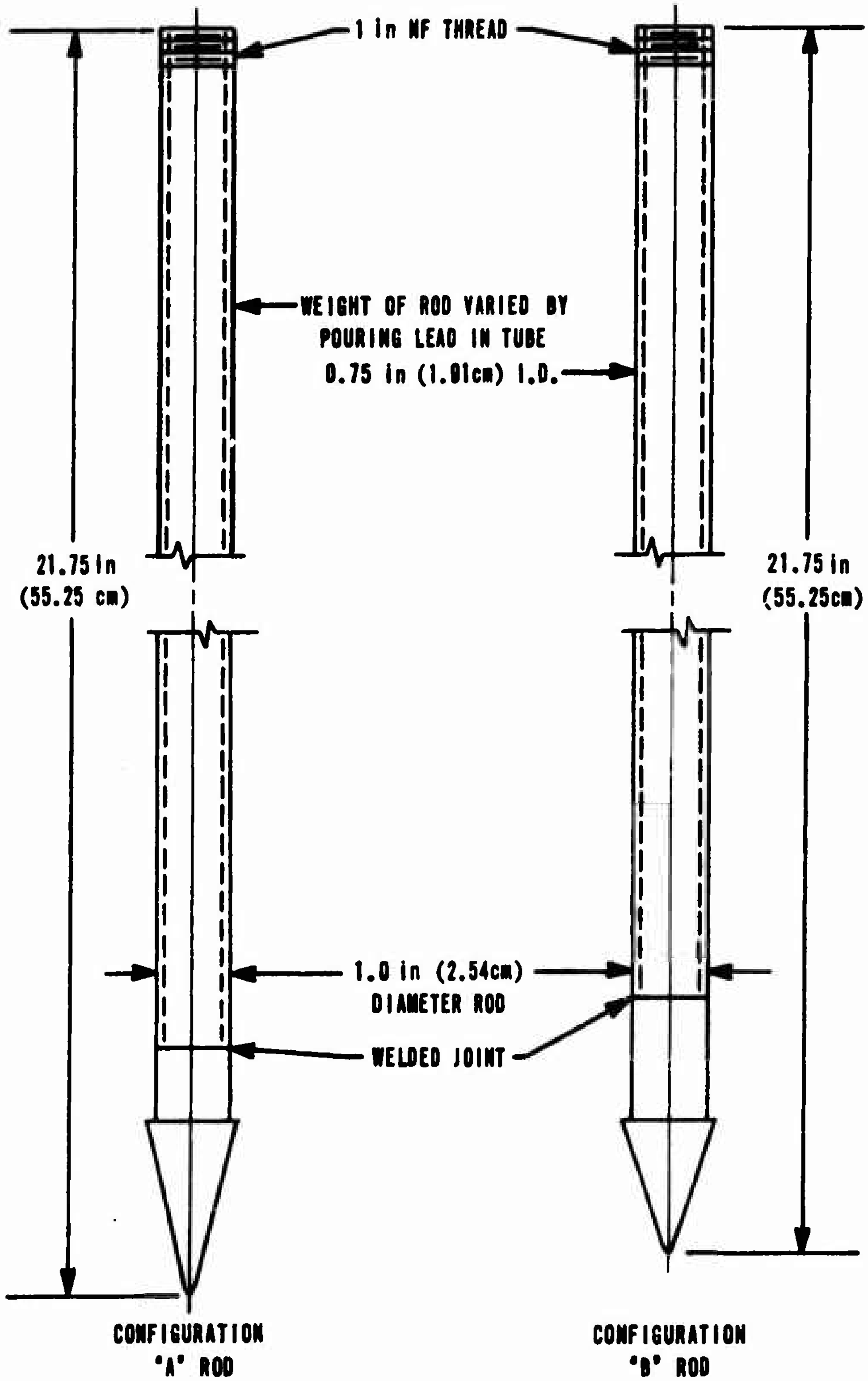

Figure 5. Center Rod Initial Design

the desired 30-inch soft-soil depth requirement. Based on the generally accepted maximum L/D of 20 to 1 for satisfactory penetrator design, the diameter of the rod was set at 1.0 inch (2.54 cm). Rod weight was increased for some of the test units by pouring lead in the hollow portion of the rod.

To hold the rod in place before impact, a 1/8-inch (0.32 cm) thick plastic shear nut was placed on the aft end of the rod. The nut was designed to shatter when the case deceleration and the rod inertial forces exceeded the strength of the plastic. The nut was also weakened at one point to ensure rod release. During part of the testing, masking tape replaced the shear nut to determine the force created by breaking the nut.

The finned portion of the case was a BDU-17/B practice bomb modified internally to receive the nylon nose adapter, a teflon rod guide and plexiglass spacers. The center-rod extended through the case and was secured by the shear nut on the threaded aft end of the rod. For simplicity of fabrication and to facilitate replacement of parts, the penetrometer was assembled using fiberglass or nylon tape.

A detailed sequence of penetrometer operation is shown diagramed in figure 6. In the pre-impact phase the penetrometer must be aerodynamically stable to achieve a predictable impact velocity and attitude for initial contact with the soil. Soon after the rod nose has penetrated and the case begins to experience soil drag, the rod begins to separate from the case. The case becomes firmly implanted while the rod continues to penetrate the soil. For hard soils (CBR 15), total penetration is designed to be approximately 18 inches (45.7 cm) with case penetration of 6 inches (15.2 cm). For soft soils (CBR 4) a total penetration of 30 inches (76.2 cm) may be expected. This includes a case penetration of 12 inches (30.48 cm). An indication of trafficability is obtained by measuring the rod separation distance.

4. PENETROMETER FIELD TESTS

All the penetrometers tested were designed for repeated use in a variety of soils so that sufficient data could be collected to adequately evaluate the technique at a minimum cost. To avoid complexity of low-angle impact (measured from the horizontal) and to ensure that each unit reached terminal velocity, all units were released at 2000 feet AGL from aircraft flying at a speed less than 100 kts. These release conditions were specified to ensure that each unit would impact within 10 degrees of the vertical, at terminal velocity, and would impact in a aerodynamically stable condition.

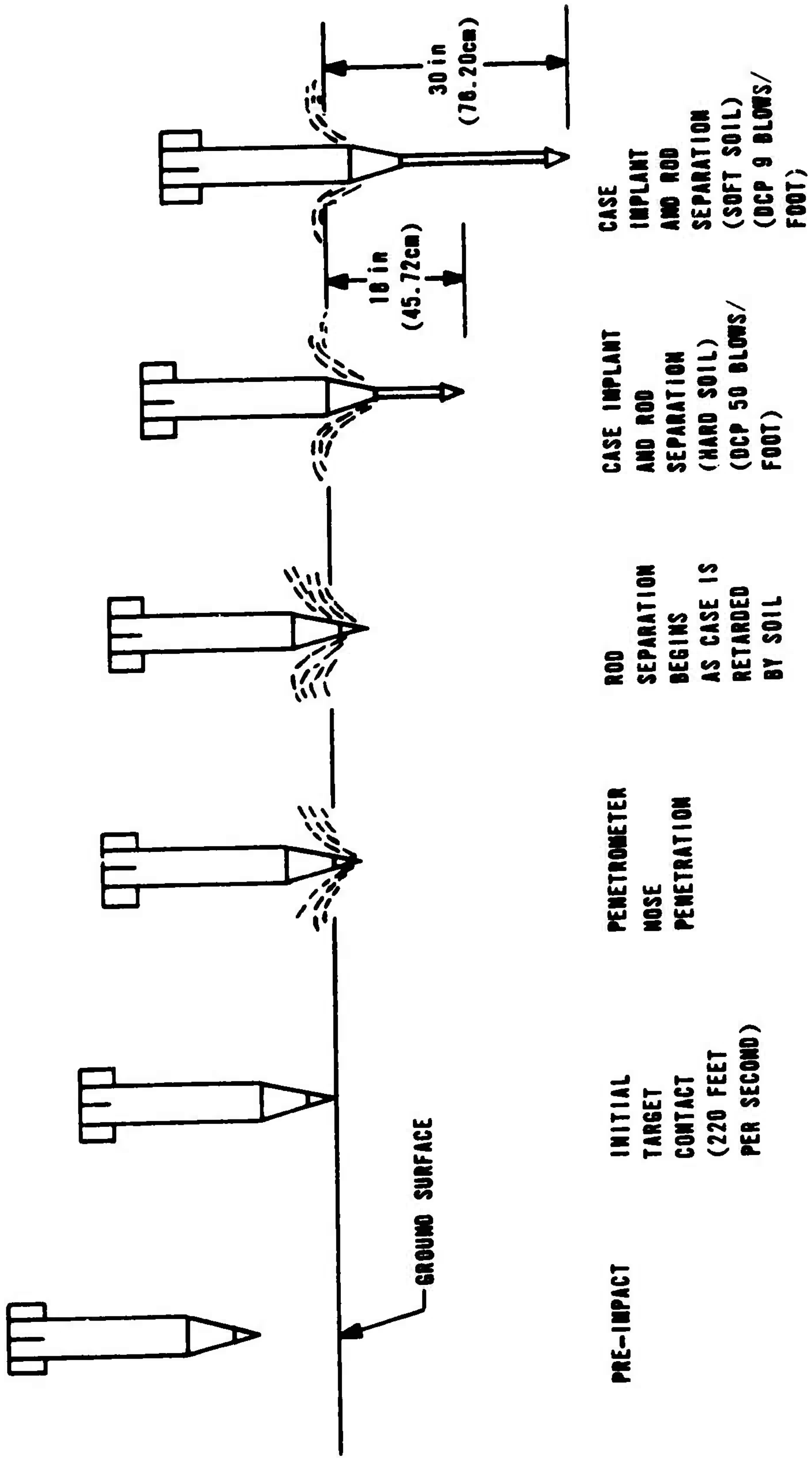

Figure 6. Penetrometer Sequence of Operation

Tests were conducted at three distinctly different locations, as outlined in table 1, to obtain performance information in hard, medium hard, and soft soils. Two series were conducted in soft soils to obtain additional data covering the design of the rod shear nut. No significant unit damage was noted from the penetrometer resting in medium hard or hard soils. Two plastic cases had to be replaced because of damage to the drag plate during testing at the soft target.

Data collected from these tests are summarized in table 2 and reference 3.

All tests produced useful results which helped define the operational usefulness of the system. Only in one test did the rod fail to separate from the case. This was caused by an insufficient decleration force that would break the shear nut on impact in very soft soil. All units were aerodynamically stable upon impact. Surface winds up to 10 kts had little effect on penetrometer performance.

5. ANALYSIS OF FIELD TEST RESULTS

The folowing analysis is based on data collected at the completion of each penetration event. Temporal data, such as deceleration, length of the event, rebound, etc., were not collected. Measurements taken were case penetration, separation distance, implant angle, total penetration, DCP and ACP readings. The DCP and ACP readings were made at 6-inch (15.2 cm) intervals at three or more locations near the implanted unit. These data were averaged for use in this analysis and are presented in tables 2 and 3. Complete information on all other aspects of the tests is shown in tables 4 through 12.

A summary of these tables shows that:

a. There were three test sites--Edgewood, Tonopah, and Bernardo--that had medium, hard, and soft soil conditions, respectively.

b. There were four tests series conducted: one with four test units at Edgewood, one with four test units at Tonopah, and two with six test units at Bernardo.

c. Four variations of the basic unit were tested. Unit A: L/D-2.0, wt 5 pounds (2.27 kg), Unit B: L/D-1.5, wt 5 pounds (2.27 kg), Unit C: L/D-2.0, wt 7.3 pounds (3.31 kg), Unit D: L/D-1.5, wt 7.2 pounds (3.27 kg). The only variations were rod weight and nose shape.

Table 1

TEST SUMMARY

Test No.	Date	No. units tested	Location	Soil type	Purpose
339234	8 Dec 70	4	Edgewood Test Site, New Mexico; operated by Sandia Laboratory	Mesa silt; thin grass; dry; medium hard	To obtain CRP aerodynamic mechanical, structural, terradynamic performance information in medium hard soils
339235	15 Jan 71	4	Tonopah Test Range, Nevada; operated by Sandia Laboratory	Dry lake playa; highly cemented sandy clayey silt	To obtain CRP aerodynamic mechanical, structural, terradynamic performance information in extremely hard soils
339236	10 Mar 71	6	Bernardo Test Site, New Mexico; operated by Sandia Laboratory	Moist to wet sandy silty clay	To obtain CRP aerodynamic mechanical, structural, terradynamic performance information in extremely soft soils
339238	30 Apr 71	6	Bernardo Test Site, New Mexico; operated by Sandia Laboratory	Moist to wet sandy silty clay	To obtain additional CRP aerodynamic mechanical, structural, and terradynamic performarce information in extremely soft soils with a modified shear device

Table 2

PERFORMANCE OF UNITS (by Test Number)

	Unit A L/D - 2.0; Wt - 5 lb				Unit B L/D - 1.5; Wt - 5 lb			
Test No.	Vel	Angle	Case pene (in)	Sep (in)	Vel	Angle	Case pene (in)	Sep (in)
339234	191	83	9.5	12.5	186	68	15.9	5.5
339234	168	88	9.0	6.8	204	84	26.9	19.2
339235	215	84	6.0	2.1	195	72	21.4	12.3
339235	217	84	6.7	2.9				
339236	195	74	21.0	13.8				
339236	201	83	16.5	10.5				
339238	186	81	28.5	0				
339238	182	83	15.0	3.5				
339238	191	87	20.5	6.0				
339238	207	76	21.0	7.8				
Avg	195.3	82.3	15.4	6.6				
	Hard soil	CBR 20						
Avg	216	84.0	6.4	2.5	---	---	---	---
	Medium soil	CBR 10-15						
Avg	180	85.5	9.25	9.7	---	---	---	---
	Soft soil	CBR 6						
Avg	197	80.7	20.4	6.9 *(8.3)	195	72	21.4	12.3
Avg	197.6	83.4	12.0	6.8	195	72	21.4	12.3

*Average when neglecting unit that failed to separate.

Table 2 (cont'd)

Test No.	Unit C L/D - 2.0; Wt - 7.3 lb Vel	Angle	Case pene (in)	Sep (in)	Unit D L/D - 1.5; Wt - 7.2 lb Vel	Angle	Case pene (in)	Sep (in)
339234	222	82	10.5	18.8	201	81	7.9	14.8
339235	247	79	7.0	10.5	243	82	6.8	12.5
339236	267	77	18.0	40.0	231	71	15.9	20.0
339238	206	86	15.0	37.7	233	75	16.4	25.0
Avg	236	81	12.6	26.8	227	77.2	11.8	18.1
	Hard soil CBR 20							
Avg	247	79	7.0	10.5	243	82	6.8	12.5
	Medium soil CBR 10-15							
Avg	222	82	10.5	18.8	201	81	7.9	14.8
	Soft soil CBR 6							
Avg	237	81.5	16.5	38.8	232	73	16.1	22.5
Avg	235.3	80.8	11.3	22.7	225.3	78.6	10.3	16.6

Table 3

PERFORMANCE OF UNITS (by Soil Description)

Unit A

L/D - 2.0; Wt - 5 lb

Soil desc	(fps)	Angle (deg)	Case pene (in)	Sep (in)	Total pene (in)	For total penetration ACP	DCP	Avg	For separation ACP	DCP	Avg
Medium	191	83	9.5	12.5	22.0	27.3	29.5	28.4	17.4	19.0	18.2
Medium	168	88	9.0	6.8	15.8	64.7	46.0	55.4	29.7	25.5	27.6
Hard	215	84	6.0	2.1	8.1	---	90.8	90.8	---	15.8	15.8
Hard	217	84	6.7	2.9	9.6	---	57.2	57.2	---	20.3	20.3
Soft	195	74	21.0	13.8	34.8	20.4	24.4	22.4	10.2	12.9	11.5
(nut)	201	83	16.5	10.5	26.5	22.0	23.9	23.0	9.1	12.9	11.0
	186	81	28.5	0	28.5	---	---	---	---	---	---
Soft	182	83	15.0	3.5	18.5	29.2	16.0	22.6	11.2	7.0	9.1
(tape)	191	87	20.5	6.0	26.5	13.7	13.1	13.4	4.7	5.2	5.0
	207	76	21.0	7.8	28.8	15.4	14.7	15.0	4.9	6.9	5.9

Table 3 (cont'd)

Soil desc	Vel (fps)	Angle (deg)	Case pene (in)	Sep (in)	Total pene (in)	For total penetration ACP	For total penetration DCP	For total penetration Avg	For separation ACP	For separation DCP	For separation Avg
Unit C — L/D - 2.0; Wt - 7.3 lb											
Medium	222	82	10.5	18.8	29.3	123.0	99.8	111.4	95.0	80.9	87.9
Hard	247	79	7.0	10.5	17.5	---	160.0	160.0	---	94.7	94.7
Soft (nut)	267	77	18.0	40.0	58.0	62.1	44.0	53.1	48.3	34.7	41.5
Soft (tape)	206	86	15.0	37.7	52.7	99.6	55.7	77.7	83.1	46.2	64.6
Unit D — L/D - 1.5; Wt - 7.2 lb											
Medium	201	81	7.9	14.8	22.7	85.3	109.0	97.2	53.3	95.0	74.2
Hard	243	82	6.8	12.5	19.4	---	170.4	170.4	---	126.0	126.0
Soft (nut)	231	71	15.9	20.0	35.9	38.2	44.5	41.3	25.9	31.5	28.7
Soft (tape)	233	75	16.4	25.0	41.4	51.6	49.4	50.5	35.4	34.2	34.8

Table 4

MECHANICAL AND STRUCTURAL PROPERTIES

Test No.	Unit No.	Nose (L/D)	Length (ref) (in)	Weight (total) (lb)	Case wt (lb)	Rod wt (lb)	Rod retain device*
339234	-1	2.0	21.2	5.04	2.60	2.44	Nut
	-2	2.0	21.2	5.04	2.60	2.44	Tape
	-3	2.0	21.2	7.30	2.60	4.70	Tape
	-4	1.5	20.6	7.20	2.70	4.50	Tape
339235	-1	2.0	21.2	5.06	2.62	2.44	Nut
	-2	2.0	21.2	5.00	2.60	2.40	Nut
	-3	2.0	21.2	7.42	2.62	4.80	Nut
	-4	1.5	20.6	7.29	2.74	4.55	Nut
339236	-1	2.0	21.2	5.04	2.60	2.44	Nut
	-2	2.0	21.2	4.99	2.59	2.40	Nut
	-3	2.0	21.2	7.42	2.59	4.83	Nut
	-4	1.5	20.6	7.25	2.69	4.56	Nut
	-5	1.5	20.6	5.19	2.70	2.49	Nut
	-6	2.0	21.2	5.06	2.58	2.48	Nut
339238	-1	2.0	21.2	5.05	2.61	2.44	Tape
	-2	2.0	21.2	5.21	2.82	2.39	Tape
	-3	2.0	21.2	7.47	2.65	4.81	Tape
	-4	1.5	20.6	7.29	2.74	4.55	Tape
	-5	1.5	20.6	5.25	2.77	2.48	Tape
	-6	2.0	21.2	5.06	2.59	2.47	Tape

*Masking tape was used to retain the rod on the units indicated.

All unit cases were assembled with nylon tape.

Table 5

AERODYNAMIC PROPERTIES

Test No.	Unit No.	Nose (L/D)	Total wt (lb)	Length (actual) (in)	Center of gravity (in)	Center of gravity (%)	Moment of pitch (lb-in²)	Inertia roll (lb-in²)
339234	-1	2.0	5.04	21.0	11.00	52.4	---	---
	-2	2.0	5.04	21.0	10.80	51.4	---	---
	-3	2.0	7.30	21.0	11.50	54.8	---	---
	-4	1.5	7.20	20.4	10.95	53.7	---	---
339235	-1	2.0	5.06	21.0	10.75	51.2	---	---
	-2	2.0	5.00	21.0	10.80	51.4	---	---
	-3	2.0	7.42	21.0	11.50	54.8	---	---
	-4	1.5	7.29	20.4	10.90	53.4	---	---
339236	-1	2.0	5.04	21.0	10.82	51.5	187.3	4.01
	-2	2.0	4.99	21.0	10.76	51.2	186.0	4.07
	-3	2.0	7.42	21.0	11.64	55.4	243.3	4.27
	-4	1.5	7.25	20.4	10.81	53.0	224.6	4.40
	-5	1.5	5.19	20.4	10.14	49.7	190.5	4.20
	-6	2.0	5.06	20.4	10.87	51.8	192.0	4.12
339238	-1	2.0	5.05	21.0	10.75	51.2	---	---
	-2	2.0	5.21	21.0	11.50	54.8	---	---
	-3	2.0	7.47	21.0	11.50	54.8	---	---
	-4	1.5	7.29	20.4	11.00	53.9	---	---
	-5	1.5	5.25	20.4	10.80	52.9	---	---
	-6	2.0	5.06	21.0	10.75	51.2	---	---

All units tested in soft soil were equipped with a 5-foot (1.52 m) trailing ribbon to aid in locating the impact point.

Table 6

TERRADYNAMIC PROPERTIES

Test No.	Unit No.	Nose (L/D)	Total wt (lb)	Rod wt (lb)	Rod W/A (psi)	Case wt (lb)	Case W/A (psi)
330234	-1	2.0	5.04	2.44	1.99	2.60	0.37
	-2	2.0	5.04	2.44	1.99	2.60	0.37
	-3	2.0	7.30	4.70	3.83	2.60	0.37
	-4	1.5	7.20	4.50	3.67	2.70	0.38
339235	-1	2.0	5.06	2.44	1.99	2.62	0.37
	-2	2.0	5.00	2.40	1.96	2.60	0.37
	-3	2.0	7.42	4.80	3.83	2.62	0.37
	-4	1.5	7.29	4.55	3.67	2.74	0.38
339236	-1	2.0	5.04	2.44	1.99	2.60	0.37
	-2	2.0	4.99	2.40	1.96	2.59	0.37
	-3	2.0	7.42	4.83	3.94	2.59	0.37
	-4	1.5	7.25	4.56	3.72	2.69	0.38
	-5	1.5	5.19	2.49	2.03	2.70	0.38
	-6	2.0	5.06	2.48	2.02	2.58	0.37
339238	-1	2.0	5.05	2.44	1.99	2.61	0.37
	-2	2.0	5.21	2.39	1.95	2.82	0.40
	-3	2.0	7.47	4.81	3.92	2.65	0.37
	-4	1.5	7.29	4.55	3.71	2.74	0.39
	-5	1.5	5.25	2.48	2.02	2.77	0.39
	-6	2.0	5.06	2.47	2.01	2.59	0.37

W = weight

A = cross-sectional area

Table 7

RELEASE CONDITIONS

Test No.	Unit No.	Target alt (ft MSL)	Release alt (ft AGL)	Release Speed (KIAS)	Surface winds (kts)	Acft
339234	-1	6500	2000	60	W/10	U-6A
	-2	6500	2000	60	W/10	U-6A
	-3	6500	2000	60	W/10	U-6A
	-4	6500	2000	60	W/10	U-6A
339235	-1	5330	2046	70 (150 fps GS)	Calm	C-47
	-2	5330	2029	70 (150 fps GS)	Calm	C-47
	-3	5330	2059	70 (150 fps GS)	Calm	C-47
	-4	5330	2032	70 (150 fps GS)	Calm	C-47
339236	-1	4600	2000	55	Calm	U-6A
	-2	4600	2000	55	E/5	U-6A
	-3	4600	2000	55	E/6	U-6A
	-4	4600	2000	55	E/4	U-6A
	-5	4600	2000	55	E/4	U-6A
	-6	4600	2000	55	Calm	U-6A
339238	-1	4600	2000	55	N/5	U-6A
	-2	4600	2000	55	N/5	U-6A
	-3	4600	2000	55	N/5	U-6A
	-4	4600	2000	55	N/7V	U-6A
	-5	4600	2000	55	N/6V	U-6A
	-6	4600	2000	55	N/5V	U-6A

All units were hand tossed from aircraft cabin.

Table 8

TRAJECTORY AND IMPACT DATA

Test No.	Unit No.	TOF (sec)	Impact vel (fps)	Impact angle (deg)	Range (ft)	Coef of drag*	Ballist coef (psf)	Surface temp (°F)	Surface winds	Remarks
339234	-1	14.66	191	85.4	751	2.811	36.5	45	W/10 gusty	Head wind; tumbled after release; stabilized at 1500 feet AGL
	-2	15.70	168	87.1	671	3.718	27.6	45	W/10 gusty	Head wind; tumbled after release; stabilized above 1500 feet AGL
	-3	13.62	222	83.1	843	2.811	52.9	45	W/10 gusty	Head wind; tumbled after release; stabilized at 1000 feet AGL
	-4	14.26	201	84.6	783	3.504	41.9	45	W/10 gusty	Head wind; tumbled after release; stabilized near 1500 feet AGL
339235	-1	14.20	215	82.0	1155	2.047	50.4	30	Calm	Unit stable at impact; initial oscillation to 1200 feet AGL
	-2	14.06	217	82.0	1160	1.963	51.4	30	Calm	Unit stable at impact; initial oscillation to 1200 feet AGL
	-3	13.41	247	79.0	1289	2.079	72.8	30	Calm	Unit stable at impact; initial oscillation to 1200 feet AGL
	-4	13.38	243	79.0	1268	2.143	69.4	30	Calm	Unit stable at impact; initial oscillation to 1200 feet AGL

Table 8 (cont'd)

Test No.	Unit No.	TOF (sec)	Impact vel (fps)	Impact angle (deg)	Range (ft)	Coef of drag*	Ballist coef (psf)	Surface temp (°F)	Surface winds	Remarks
339236	-1	14.48	195	85.4	712	2.543	40.4	60	Calm	
	-2	14.25	201	85.0	730	2.335	43.5	60	E/5	Head wind
	-3	12.56	267	80.6	881	1.551	97.5	60	E/6	Head wind; slight unit roll observed
	-4	13.34	231	82.9	806	2.376	62.2	60	E/4	Head wind; slight unit roll observed; oscillation at 200 feet AGL
	-5	14.79	186	82.0	688	2.878	36.7	60	E/4	Head wind; slight unit roll observed
	-6	14.96	186	86.2	676	2.942	35.0	60	Calm	Head wind; slight unit roll observed
339238	-1	14.98	182	86.3	674	2.958	34.8	80	N/5	Left crosswind; slight unit roll observed
	-2	14.62	191	85.7	700	2.670	38.6	80	N/5	Left crosswind; slight unit roll observed
	-3	14.06	206	84.6	745	3.278	46.4	80	N/5	Left crosswind; required time to stabilize
	-4	13.31	233	82.8	810	2.351	63.2	80	N/7 variable	Left crosswind; slight yaw observed
	-5	14.16	204	84.8	737	2.383	44.9	80	N/6 variable	Left crosswind; slight yaw observed
	-6	14.04	207	84.5	746	2.207	47.7	80	N/5V variable	Left crosswind; slight roll observed

*CD based on a reference area of 0.04909 square feet.

Table 9

IMPLANT INFORMATION

Test No.	Unit No.	Nose (L/D)	Unit wt (lb)	Implant angle (deg)	Case pene (in)	Rod sep (in)	Total pene (in)	Description
339234	-1	2.0	5.04	83.5	9.5	12.5	22.0	Stable; solid; tight; very little crater
	-2	2.0	5.04	88.5	9.0	6.8	15.8	Stable; solid; tight; very little crater
	-3	2.0	7.30	82.0	10.5	18.8	29.5	Case loose; nose tight; 8-inch wide, 2-inch deep crater
	-4	1.5	7.20	81.0	7.9	14.8	22.7	Stable; slightly loose
339235	-1	2.0	5.06	84.5	6.0	2.1	8.1	Stable; rigid; 5-inch wide, 1-inch deep crater in ice
	-2	2.0	5.00	(84.5)	(6.7)	(2.9)	9.6	Stable; tight; very little crater
	-3	2.0	7.42	79.0	7.0	10.5	17.5	Stable; solid; aft spacer failure
	-4	1.5	7.27	82.0	6.3	12.5	19.3	Stable; rigid; 1/4-inch crater around unit

Table 9 (cont'd)

Test No.	Unit No.	Nose (L/D)	Unit wt (lb)	Implant angle (deg)	Case pene (in)	Rod sep (in)	Total pene (in)	Description
339236	-1	2.0	5.04	74.0	21.0	13.8	34.8	Firm 3/4-inch crater around unit body
	-2	2.0	4.99	83.0 (Rod 83.5)	16.5	10.5	27.0	Firm 3/4-inch crater around unit body
	-3	2.0	7.42	77.0	18.0	40.0	58.0	First to solid, stable, small gap around aft body
	-4	1.5	7.25	71.0	15.9	20.0	35.9	Firm but at low angle; large crater
	-5	1.5	5.19	68.0	15.9	5.5	21.4	Solid implant; 1-inch gap front side
	-6	2.0	5.06	81.0	28.5	0.0	28.5	Complete burial
339238	-1	2.0	5.05	83.0	15.0	3.5	18.5	Solid; gap around aft part of body
	-2	2.0	5.06	87.0	20.5	6.0	26.5	Solid; gap around other part of body
	-3	2.0	7.47	86.0	15.0	37.7	52.7	Solid; tilted slightly
	-4	1.5	7.29	75.0	16.4	25.0	41.4	Firm; large ejecta
	-5	1.5	5.25	84.0	26.9	19.2	46.1	Solid; full burial
	-6	2.0	5.06	75.0	21.0	7.8	28.8	Solid; flush with surface

Table 10

AIRFIELD CONE PENETROMETER DATA

Test No.	Unit No.	No. Rdgs. Taken	Average ACP reading for each depth indicated (in)								
			0	3	6	9	12	18	24	30	36
339234	-1	2		6.5	6.0	6.5	6.5	8.5	9.5	---	---
	-2	2		7.5	21.5	27.0	29.0	22.5	17.5	---	---
	-3	2		7.5	14.5	19.0	26.5	30.0	25.0	---	---
	-4	3		11.3	26.3	24.5	20.0	21.5	22.5	---	---
339235	-1	0	Soil was too hard to obtain ACP data								
	-2	0	Soil was too hard to obtain ACP data								
	-3	0	Soil was too hard to obtain ACP data								
	-4	0	Soil was too hard to obtain ACP data								
339236	-1	3	1.0	1.0	1.3	2.7	3.3	3.7	3.8	4.7	4.5
	-2	3	1.0	2.3	3.1	4.1	5.5	5.8	5.3	5.8	11.0
	-3	4	1.4	1.5	1.5	3.8	5.8	6.5	7.5	6.8	7.0
	-4	3	1.0	1.0	3.0	5.7	7.0	13.0	7.7	10.0	16.3
	-5	4	0.0	1.0	1.2	3.2	3.8	4.8	4.9	7.6	11.2
	-6	3	0.0	1.0	1.7	3.0	4.7	9.2	10.7	11.3	12.0
339238	-1	3	2.0	2.0	2.0	3.5	5.5	21.0	8.3	8.5	12.7
	-2	3	1.5	1.5	1.5	1.5	2.2	3.7	3.8	3.5	6.7
	-3	3	2.0	2.0	3.0	5.0	6.7	7.7	5.0	6.0	10.0
	-4	4	2.0	2.0	2.5	3.9	4.9	11.7	6.9	5.8	10.8
	-5	3	2.0	2.0	2.0	2.0	3.7	4.7	4.7	6.7	9.7
	-6	3	2.0	2.0	2.0	2.0	2.0	4.5	4.0	3.6	5.3

Table 11

DYNAMIC CONE PENETROMETER DATA

Test No.	Unit No.	No. Rdgs Taken	Average DCP Reading, Blows per Each 6-Inch Layer Indicated 6	12	18	24	30	36	42
33923	-1	3	6.0	7.7	10.0	8.7	---	---	---
	-2	3	9.3	22.3	22.7	15.7	---	---	---
	-3	2	5.5	20.0	31.5	22.5	---	---	---
	-4	2	10.0	32.5	20.0	23.5	---	---	---
339235	-1	1	75.0	45.0	---	---	---	---	---
	-2	1	32.0	42.0	---	---	---	---	---
	-3	1	56.0	51.0	58.0	---	---	---	---
	-4	1	48.0	43.0	64.0	---	---	---	---
339236	-1	3	1.0	1.7	6.0	5.7	4.0	4.0	---
	-2	4	1.0	4.6	7.3	9.0	5.0	6.0	---
	-3	3	1.0	3.3	5.0	4.3	5.7	4.7	---
	-4	4	0.5	4.3	12.8	15.3	6.0	5.7	---
	-5	3	0.0	3.0	7.0	5.7	3.3	5.0	---
	-6	3	0.3	1.7	2.7	6.7	7.0	9.0	---
339238	-1	3	0.3	2.7	12.0	16.3	6.3	4.7	(9.0)
	-2	3	0.0	1.0	4.3	6.3	3.7	2.7	7.7
	-3	3	1.3	4.7	7.0	7.3	4.0	6.7	8.7
	-4	3	0.0	6.0	12.7	12.7	3.7	5.0	(9.5)
	-5	3	0.0	1.3	3.3	4.0	4.1	6.3	---
	-6	3	0.0	1.3	3.7	5.7	5.0	3.0	(6.0)

Table 12

PENETROMETER CASE SURVIVABILITY DATA

Test No.	Unit No.	Unit Weight (lb)	Avg. G Level	Peak G	Remarks
339234	-1	5.04	717.5	1794	
	-2	5.04	583.9	1460	
	-3	7.30	869.9	2175	
	-4	7.10	950.6	2377	Center Spacer Failed
339235	-1	5.06	1434.8	3587	
	-2	5.00	1306.2	3266	
	-3	7.43	1633.2	4083	Aft Spacer Failed
	-4	7.30	1607.2	4018	
339236	-1	5.04	337.2	843	
	-2	4.99	454.6	1137	
	-3	7.42	738.0	1845	
	-4	7.25	623.5	1559	
	-5	5.19	404.0	1010	
	-6	5.06	225.7	564	Drag Plate Broken
339238	-1	5.05	411.4	1029	
	-2	5.06	331.3	828	
	-3	7.47	527.2	1318	
	-4	7.29	615.3	1538	
	-5	5.25	288.5	721	
	-6	5.06	380.2	950	1/4 of Drag Plate Broken

d. Units A, C, and D were tested in all test series. Unit B was dropped only at the two series conducted at Bernardo and showed undesirable performance characteristics compared with the other units.

e. Petrometers were dropped from a C-47 at Tonopah and a U-6A (Beaver) elsewhere.

f. A shear nut and tape were used to retain the rod and case together at Edgewood and for one test series at Bernardo. Tests at Tonopah used the shear nut.

The results of all tests are shown in table 2. An examination of the average performance of the various units showed that nose shape makes only a small difference in impact velocity but significantly influences the implant angle. Implant angle and case penetration are slightly greater for nose L/D = 2.0. The effects of nose shape on separation distance, however, are difficult to evaluate because of the limited data and the variation in rod weight between units C and D. A separation of data by soil type shows essentially similar relationships.

The effect of additional rod weight is dramatic in providing increased impact velocities. The 40-percent greater ballistic coefficient of the heavier units produces 20 to 30 feet per second higher impact velocities. It is interesting to note that unit A shows a greater impact angle than unit C. This difference although only 1 or 2 degrees, probably is caused by the higher overturning moment of the heavier rod in unit C upon impact with the soil surface. Case penetration and rod separation are much greater with the heavier units. It should also be noted that in soft soils the deviation from the mean penetration is much less for the heavy units than for the light units.

Average values in table 2 were calculated by two methods. The first average is based on all drops made with a particular unit. It provides a lumped average which tends to be weighted toward performance in soft soils because of more tests conducted in soft soils. The second average is associated with the unit's performance in various hardnesses of soils. This is a truer average since it is equally weighted for performance in each hardness of soil. It is interesting to note that the same trends apply to both types of averages although variations are much more pronounced in the second set of average values.

To more effectively evaluate the performance of each unit with respect to others, a series of graphs was prepared (figures 7 through 9).

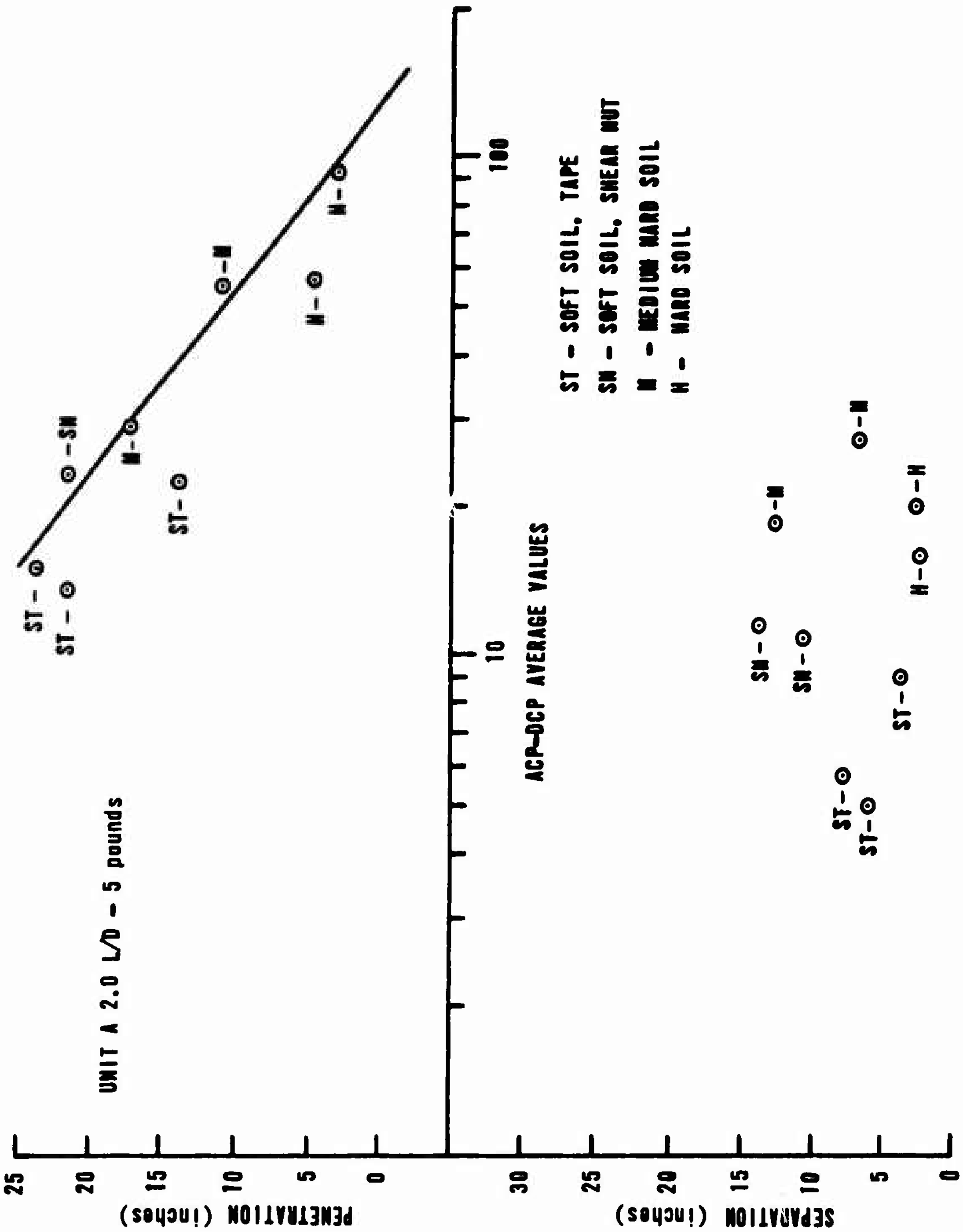

Figure 7. Penetration and Separation versus Average ACP-DCP Values, Unit A

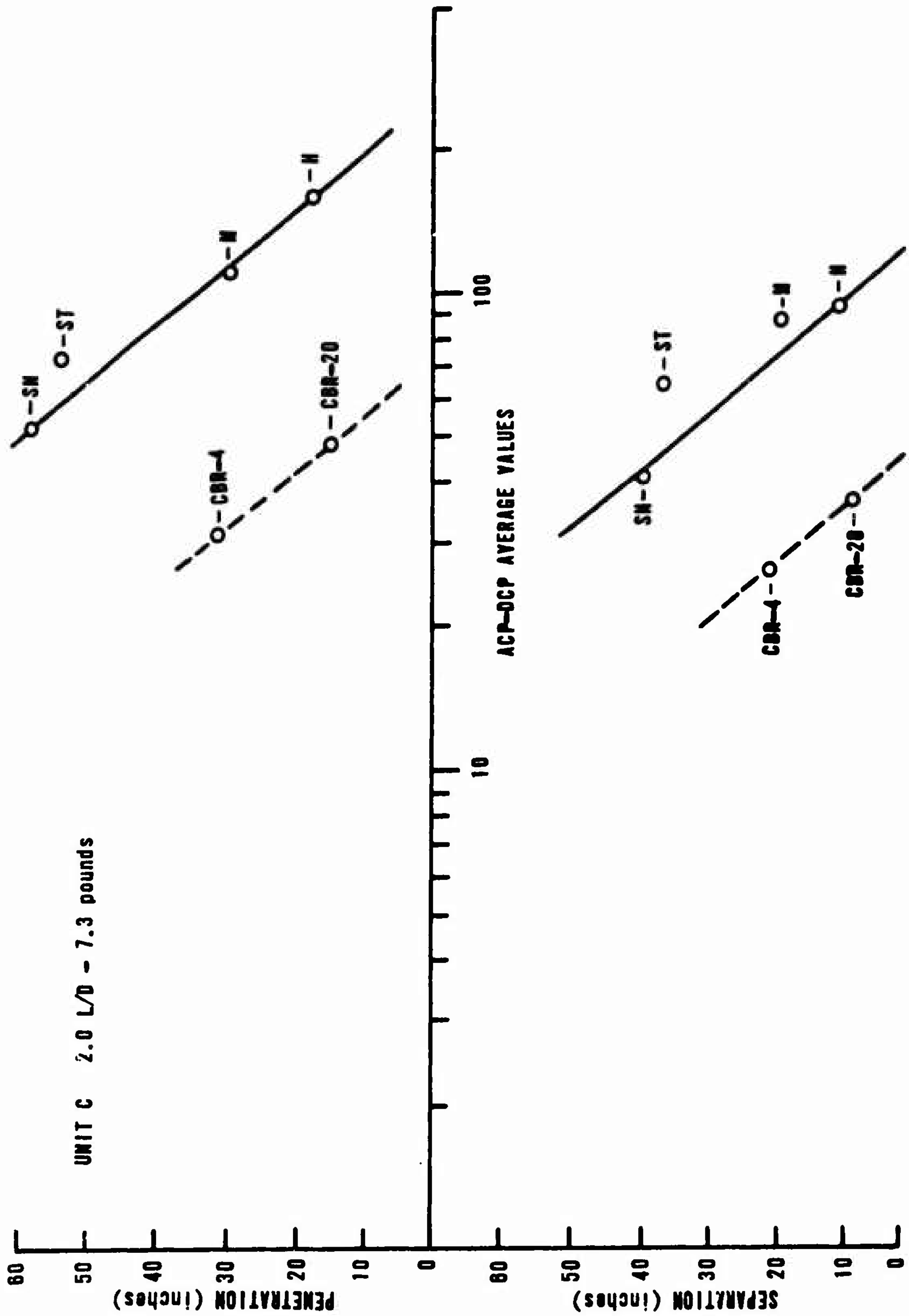

Figure 8. Penetration and Separation versus Average ACP-DCP Values, Unit C

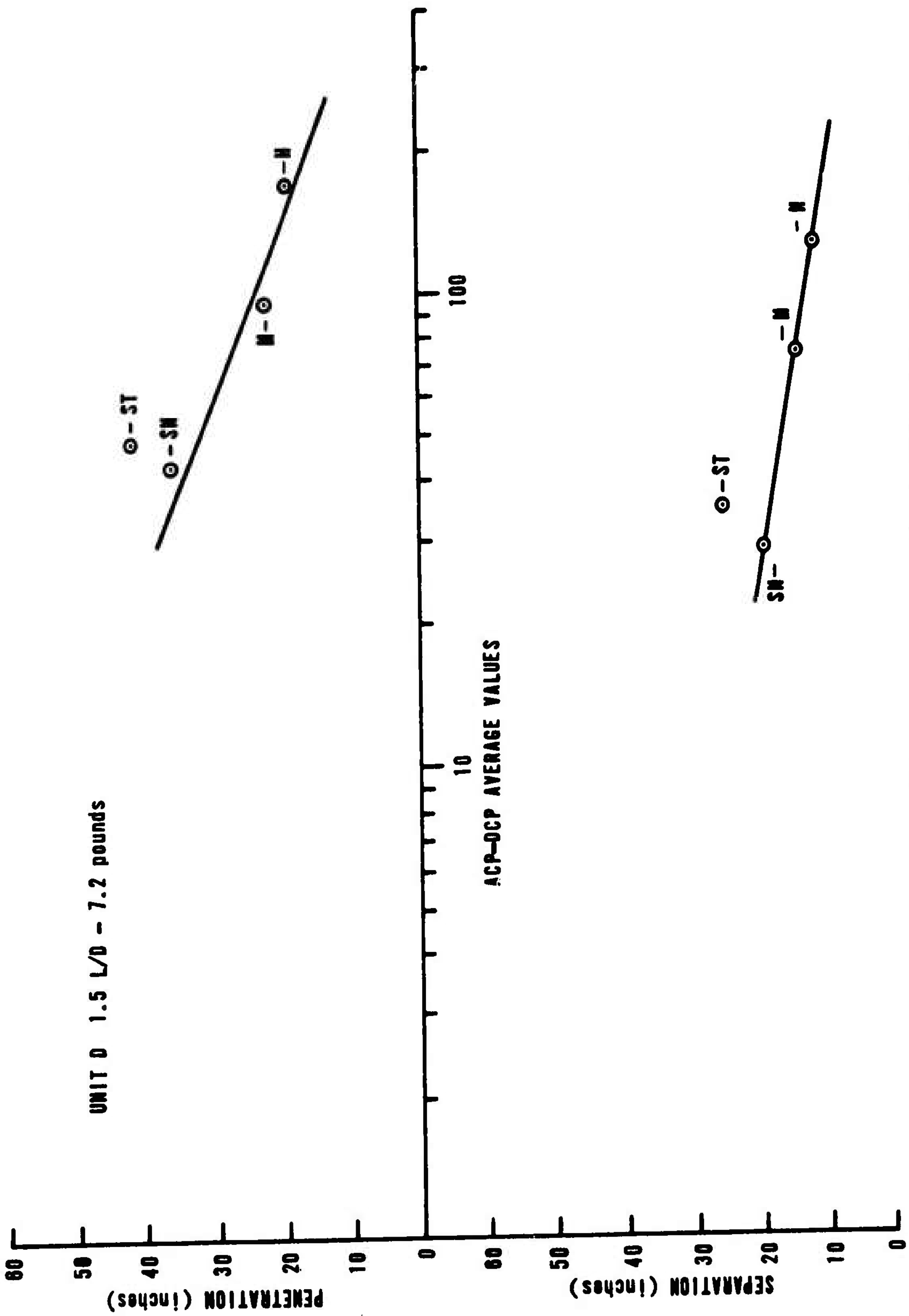

Figure 9. Penetration and Separation versus Average ACP-DCP Values, Unit D

Data presented in table 3 were used to plot these graphs. The cumulative values of ACP and DCP were obtained over the total penetration of the rod. The cumulative values of ACP and DCP for the case penetration were subtracted from the total ACP and DCP penetration figures to obtain separation total.

This type of analysis takes into account the effects of increasing or decreasing hardness of the soil. Separation in this type of analysis is based only on soil strength below the case implant depth. This may or may not be a proper analysis depending on where rod separtion begins. Time histories of the penetration event should provide the data required to make this type of determination.

Figures 7 through 9 show the relationships that exist between penetrations, separation, and ACP-DCP averages for each of the units. Table 13 gives hypothetical cases that were selected to provide representative values for the range in soil strengths of interest. These values are plotted in figure 7.

Table 13

HYPOTHETICAL PENETROMETER PERFORMANCE*

Actual CBR at Soil Depths										
Soil Depth (in.) / Hypo. CBR	6	12	18	24	30	Case Pene. (in)	Sep. Dist. (in)	Total Pene. (in)	Total CBR Pene.	Total CBR Sep.
4	2	5	6	8	9	10	21	31	31.5	26.2
20	7	24	35	47	40	7	8	15	48.5	37.5

* Shown as dashed line on graph for unit C (figure 8).

Figure 7 shows a well-defined relationship between penetration and the ACP-DCP average for unit A. In the soft soil, attempts at prediction would be very difficult because of the scatter in data for the ACP-DCP below 25. This scatter of data and the data scatter shown where separation versus ACP-DCP count are compared in figure 7 and can be explained by the fact that the rod and case are very close to the same weight. Separation between rod and case does not occur as consistently as with heavier rod weights. This delay or variation in separation is even more pronounced for soft soils.

No graphs were prepared on unit B because data were not available.

Unit C displayed predictable trends for both total penetration and separation versus ACP-DCP average (figure 8). The units held together by tape had higher total penetration and separation than those held by shear nuts. The slope of the lines for the experimental data is very close to the slope of the projected hypothetical cases.

The graphs for unit D (figure 9) also show predictable trends for penetration and separation versus ACP-DCP averages. Scatter is less for the separation curve than for the penetration curve for this unit while for unit C the scatter was greater for the separation curve than for the penetration prediction curve. The reason for these differences in scatter is not known. The slope of the prediction lines is influenced by nose shape. It is steeper for nose shapes with larger length-to-diameter ratios.

Based upon these analyses, and L/D of 2.0 to 1.0 and a rod weight roughly double the case weight was selected. Table 14 provides projected performance and cost information. The amount of separation rather than total penetration was selected as a consistent measure of soil response. These selections of the basic design parameters and the successful completion of testing prompted work on the development of a reliable telemetry system.

Table 14

PROJECTED PERFORMANCE AND COST INFORMATION

Aerodynamics (sea level)

Total Unit Weight (lb)	Nose Config. Cone (L/D)	Center of Gravity(max)	Drag Coef	Rel. Alt. AGL (ft)	Rel. Vel. (kias)	Range (ft)	TOF (sec)	Impact Angle (deg)	Impact Vel. (fps)	Ballistic Coef W/DPA
7.0	1.5	50%	2.14	2000	100	13.9	13.9	82	225	66.6

Terradynamics

Total Unit Weight (lb)	Nose Config. Cone (L/D)	Impact Angle (deg)	Impact Vel. (fps)	Case Wt. (lb)	Case W/A (psi)	Rod Wt. (lb)	Rod W/A (psi)	Soil	Case Pene. Dist (in)	Rod Pene. Dist. (in)	Rod Sep. (in)
7.0	1.5	82	225	2.0	0.283	5.0	4.074	Soft	14.0	36.0	22.0
7.0	1.5	82	225	2.0	0.283	5.0	4.074	Hard	4.5	18.0	13.5

Unit Cost Estimate

	Case	Rod	Telemetry	Total
Cost	$3.00	$2.00	$20.00	$25.00

SECTION III

TELEMETRY SYSTEM

1. PAST PROGRAM REVIEW

Efforts with the center rod penetrometer telemetry system began with evaluation of the Atlantic Research Telemetry System. This system used a resistor string with a knife blade on the center rod which cut grounding straps from the resistors, thereby generating a voltage staircase to indicate separation. The transmitter was a self-excited Hartley oscillator whose frequency was highly voltage sensitive. By using the voltage staircase as a voltage source, an FM system resulted. The antenna was a stub without a ground plane.

In an attempt to improve the reliability of the telemetry system, three different transmitters, two pickup systems, and several antennas were developed.

Primarily because of mechanical considerations, a magnetic pickup and a rod with magnetic discontinuities was developed to replace the resistor string. The pickup used was a field sensitive transistor. Although this system worked reasonably well, it was susceptible to RF feedback problems and was subsequently replaced with an optical sensor. The sensor used is a Texas Instrument TIL 139 which includes a light-emitting diode as a light source and a phototransistor for a pickup. The rod has alternating light and dark bands. Through an amplifier the sensor output frequency modulates the transmitter. This system has been quite satisfactory, although it has some tendency to oscillate at the transition reflective level and requires the black coatings on the rod to be in good condition. During later testing a Schmitt squaring circuit was incorporated to eliminate this oscillation tendency.

A great effort was expended to provide low cost transmitters for production units. Because of its amplitude noise rejection characteristics, an FM system was a logical choice for the telemetry. This was particularly true in this case where severe amplitude perturbations due to antenna pattern and ground reflections could be expected. It was difficult to design an FM transmitter simple enough to be inexpensive, yet sophisticated enough to survive the expected environment. To transmit the low frequencies encountered as the rod comes to a stop, the system must have near DC response. This inferred true FM was necessary and

not the easier to obtain phase modulation. True FM of a crystal-controlled system requires a low oscillator frequency with numerous multipliers to secure a usable amount of deviation (signal) at the receiver. The complexity, hence cost, is high. A self-excited oscillator however is easily frequency modulated to almost any desired degree and can operate at the output frequency. This was the approach used in the Atlantic Research unit and was the basis of the early transmitters in this program. Although these transmitters meet the modulation requirements, their center frequency stability is so poor that they are unstable. Three transmitters were designed with progressively more stages in an attempt to isolate the oscillator from the impact environment which caused it to shift out of the frequency channel. These shifts are believed to be the result of changes in the load on the transmitter when the antenna near-field is affected by ground and by the movement of the metallic rod when it separates.

One test was run using a commerical crystal controlled FM transmitter. The transmitter stayed in channel, but the overall results were inconclusive because of an apparent bandwidth limitation somewhere in the system.

2. CURRENT SYSTEM

Figure 10 depicts the present telemetry system. Based on early failures, a crystal-controlled transmitter is considered vital to the telemetry system. A previous design which was proved readily reproducible and inexpensive was available. This is a three-stage 130-MHz amplitude-modulated (AM) transmitter (figures 11 and 12). The modulator (figure 13) is not linear but simply switches on or off, which is tantamount to 100 percent amplitude (A). It could possibly be used as an AM system except that receivers do not normally respond to DC, so that there would be problems as the rod came to a stop. It would, of course, also respond to the previously mentioned transmission variations. Because of this, the desired information is impressed on a 40-kHz FM subcarrier. Since these data are contained in frequency only, the received AM can be treated in much the same manner as FM. For instance, it can be limited to control amplitude variations. This results in a system with the required stability, yet simple enough to be relatively inexpensive.

Because the addition of the subcarrier made a new audio circuit board (figure 14) necessary, the input circuitry was redesigned to include a high hysteresis Schmitt trigger driven by the photosensor. The inclusion of this device eliminates the oscillation tendency, and its noise-handling characteristics greatly reduce

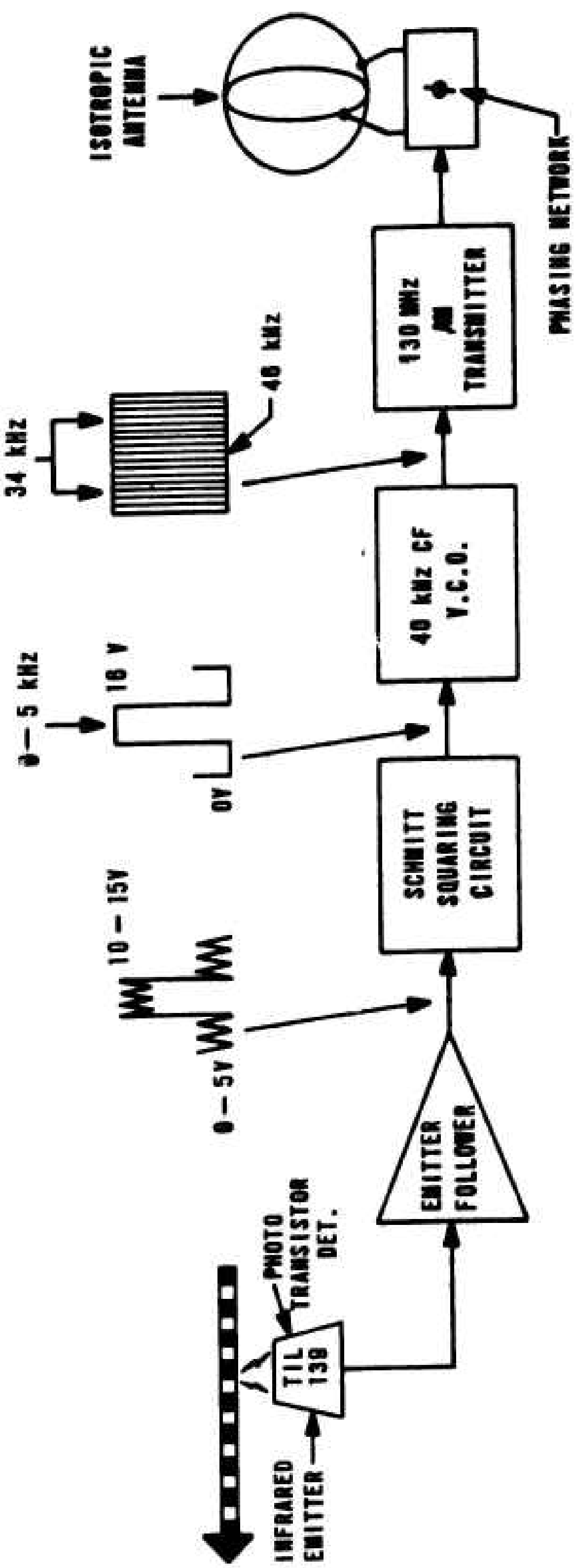

Figure 10. Telemetry System

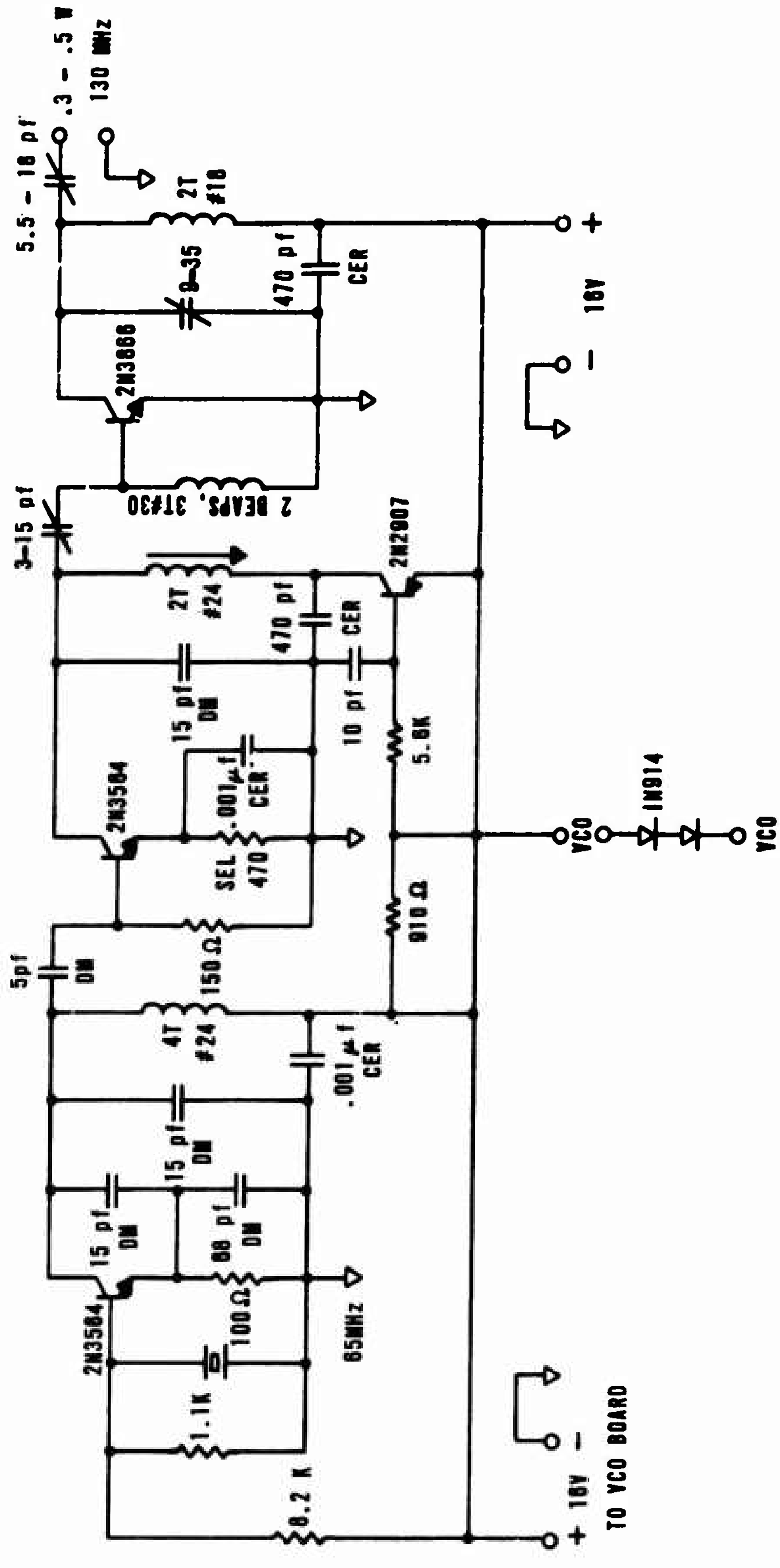

Figure 11. Transmitter Schematic

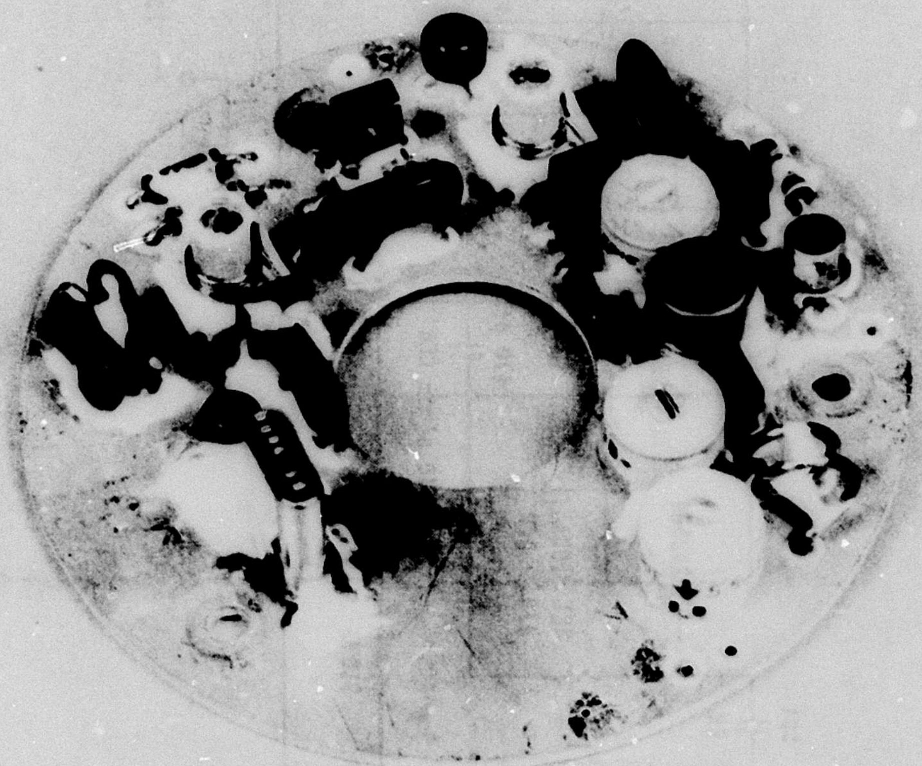

Figure 12. Transmitter Circuit Board

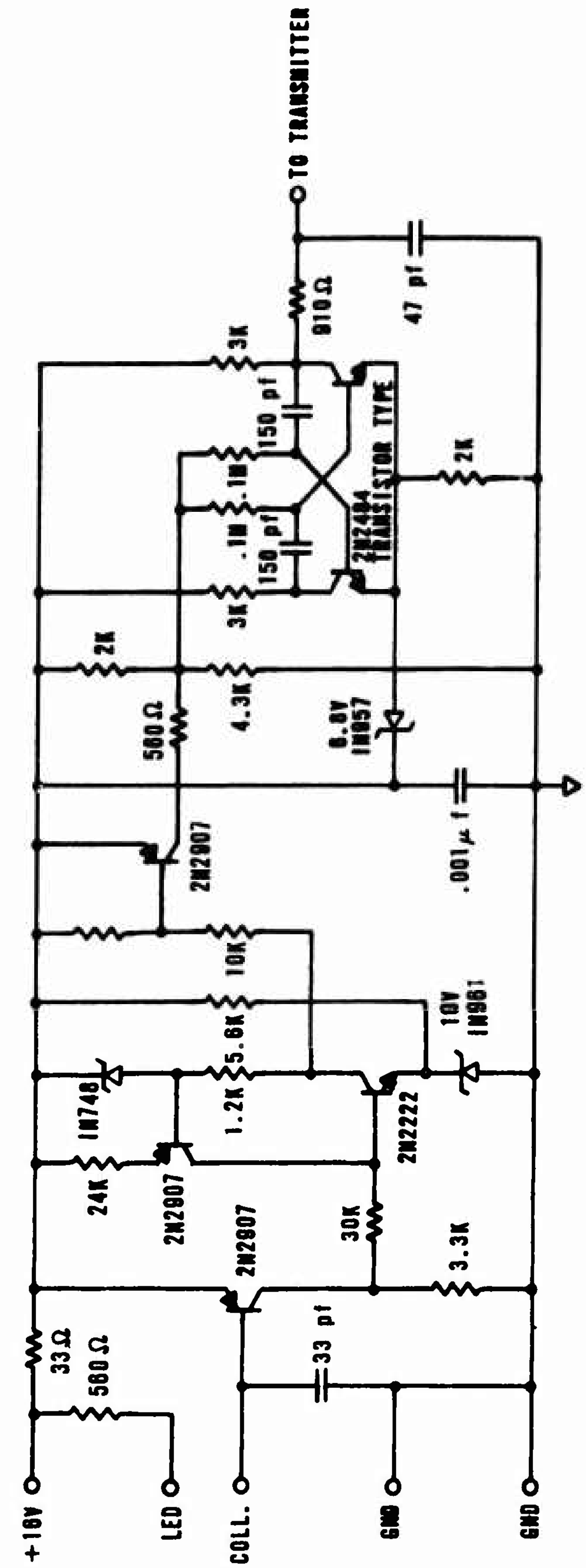

Figure 13. Modulator Schematic

Figure 14. Modulator on VCO Circuit Board

the quality requirement for the light and dark banding on the rod. The photosensor is operated in a grounded emitter system to reduce decay time.

The last problem area was the antenna. The movement of the metallic rod when it separates has had major effects on antenna turning, resulting in the loading variations believed to have caused the previously discussed frequency shifts.

Two new antennas were developed. The first was a short loop made in the form of an additional fin 5 inches long and 1-1/4-inches high. The outside of the case was to be metallized for form one side of the loop. A hand-made model of this antenna was constructed and operated satisfactorily with very small effects from rod movement or ground proximity. However, because this fin made the unit asymetric, there may have been an adverse effect on vehicle ballistics. In soft soil the case could be buried beyond the antenna location. For these reasons, the antenna was moved to the aft section of the unit. The second and current design consists of orthogonally mounted loops approximately 3.5 inches in diameter potted in foam (figures 15 and 16). The two loops are fed in phase quadrature. Two magnetic dipoles operated in this manner become an isotropic radiator except as modified by objects in its near field. The polarization changes from vertical to horizontal around the antenna sphere. The pickup, amplifier, voltage controlled oscillator (VCO), and transmitter are constructed in one module (figures 17 and 18). The nicad battery pack is located above the electronics module (figures 19 and 20). The remaining space is filled with a foam plug. Turn-on, battery charging, and antenna cables will be available on the antenna mounting plate. The rod restraint is changed from the previous plastic nut to a nose-cone shear pin to accommodate the proposed antenna configuration. Figures 20, 21, and 22 show major subassemblies and final assembly of the penetromenter.

3. FIELD PERFORMANCE

There have been 17 drops on the three units all from a height of about 600 feet. Thirteen have used the original unit. There have been two failures. The first failure resulted from attaching the nose cone to the main body with four screws. On the first drop the nose cone separated at the attach point. This also tore the antenna cable loose from the package. Since then, the nose has been attached with tape and the antenna cable has a one-turn coil as a strain relief, and no further difficulities have been encountered. The second failure

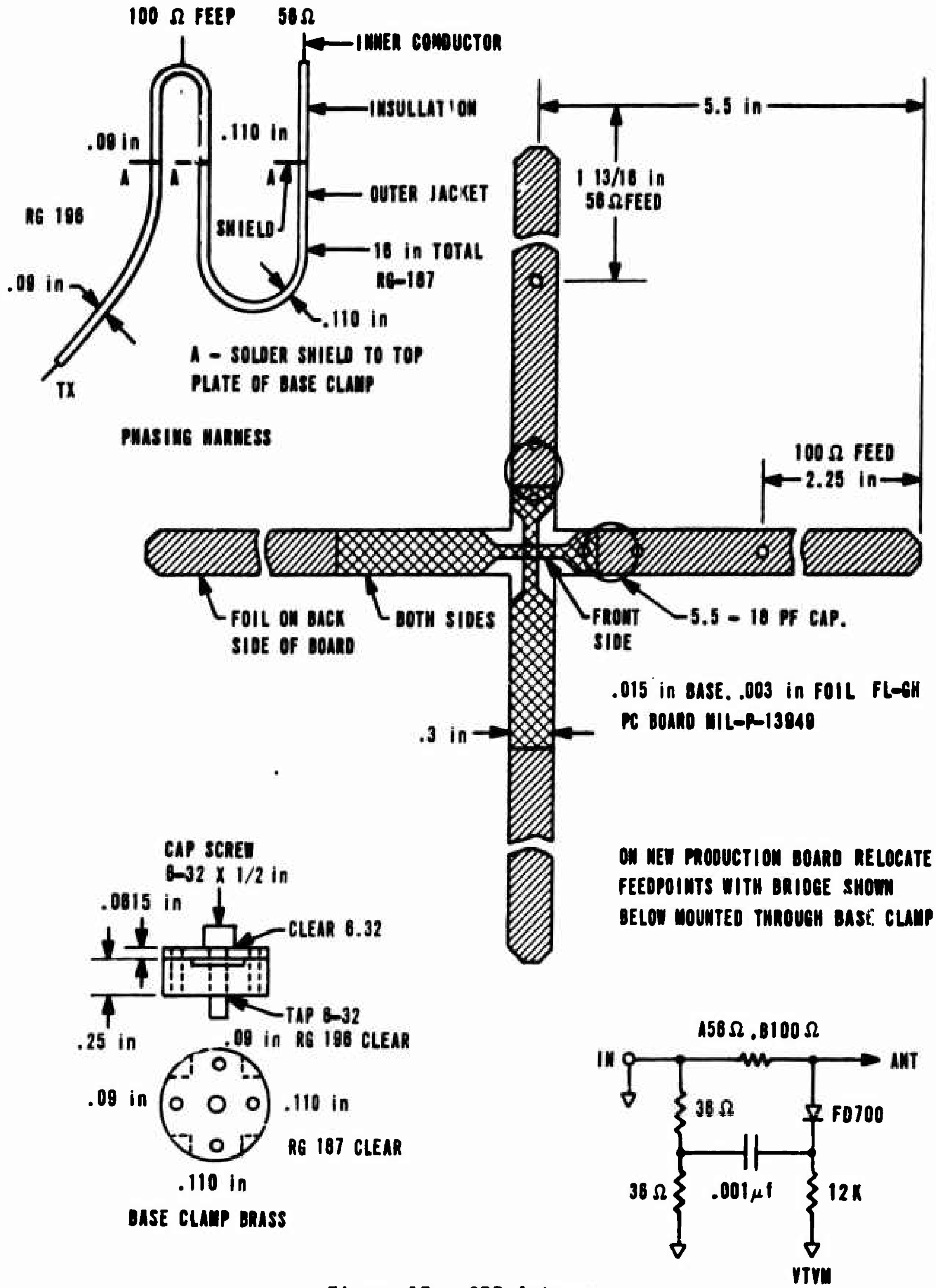

Figure 15. CRP Antenna

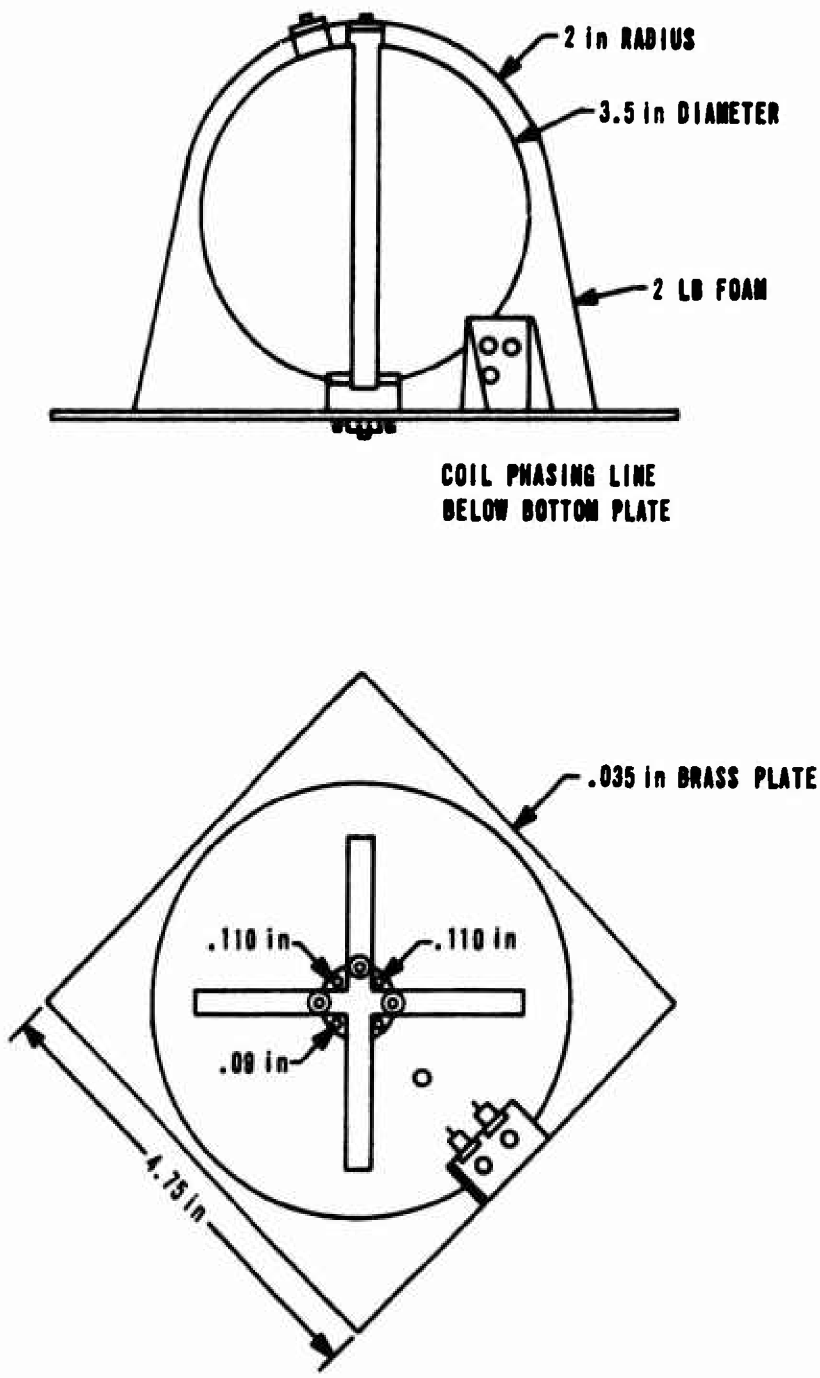

Figure 16. CRP Antenna Assembly

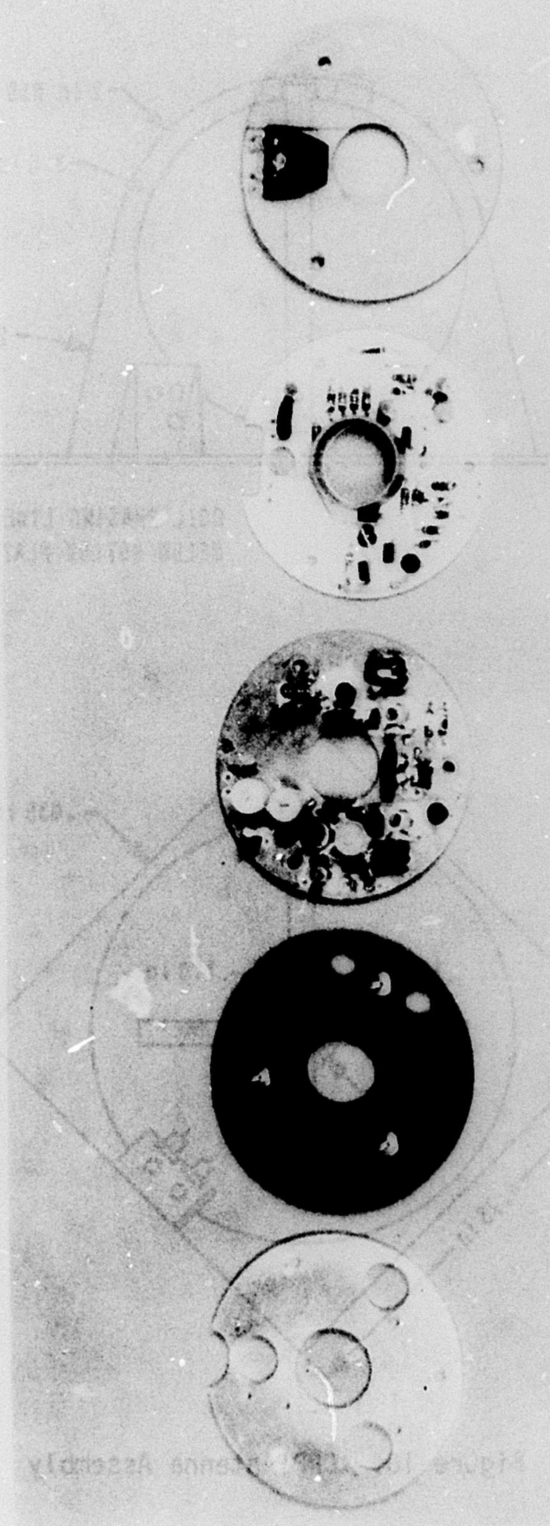

Figure 17. Disassembled Telemetry Module

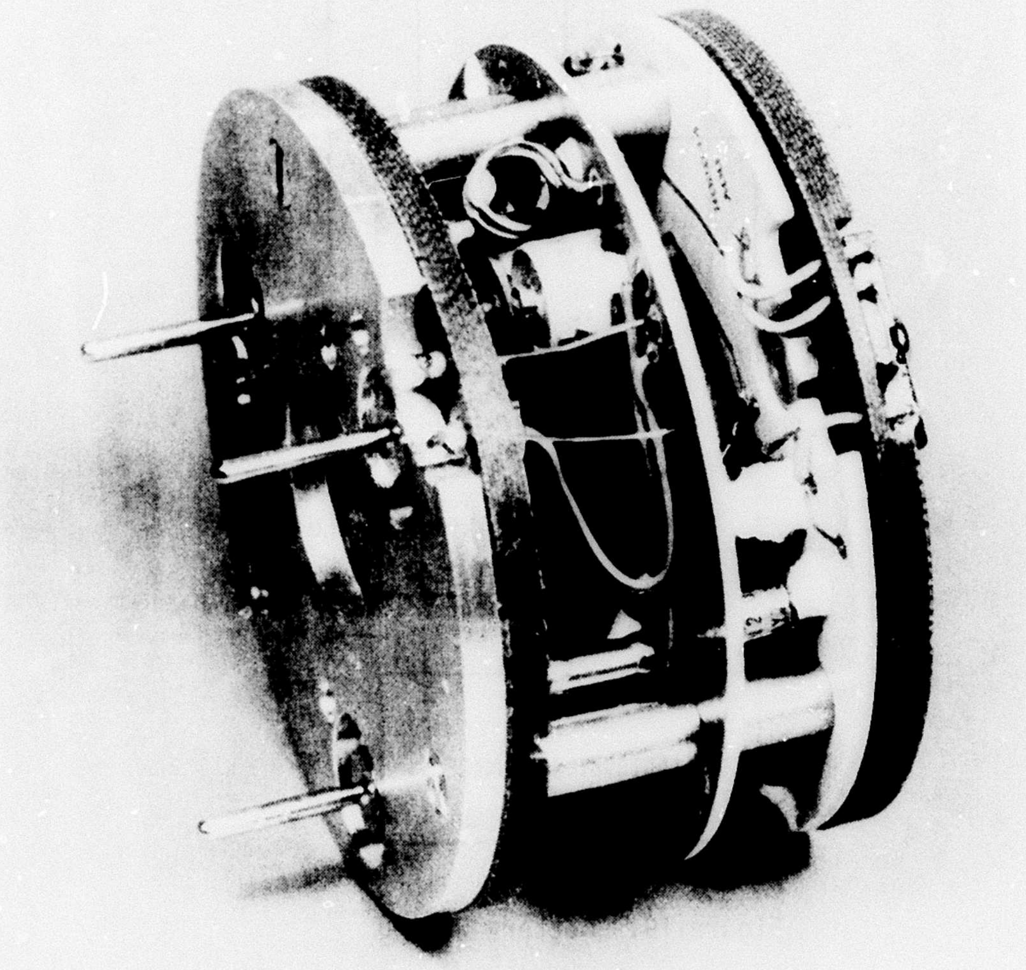

Figure 18. Telemetry Module

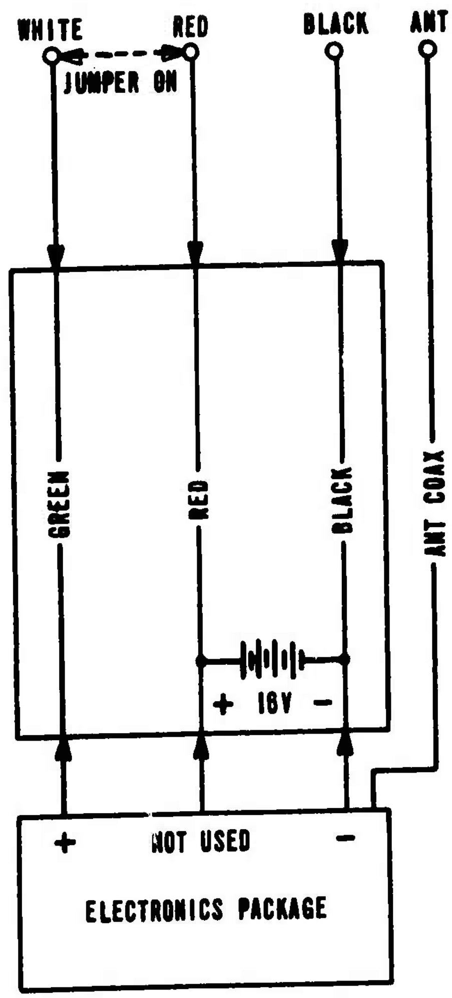

Figure 19. Battery Wiring

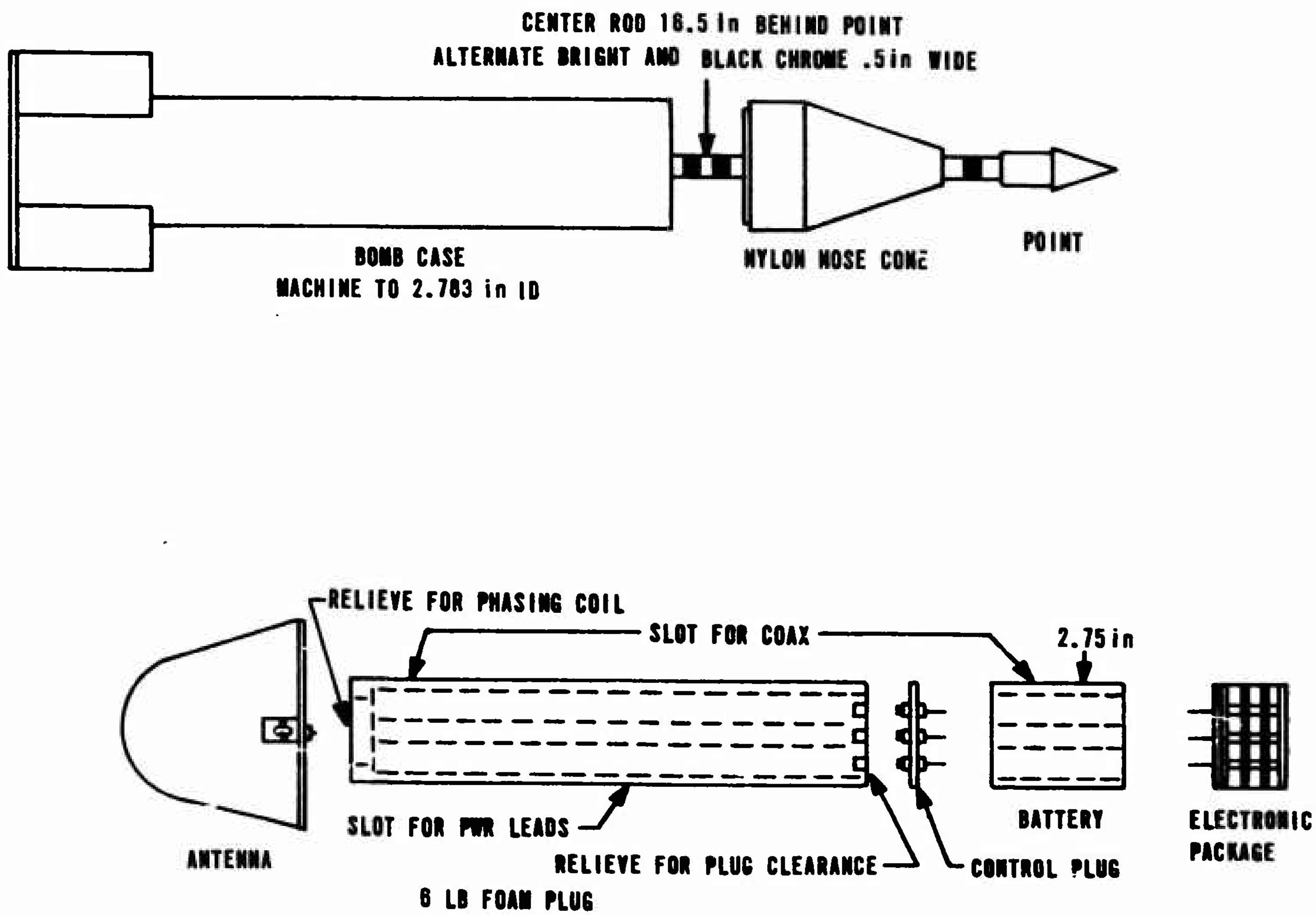

Figure 20. Penetrometer Assembly Details

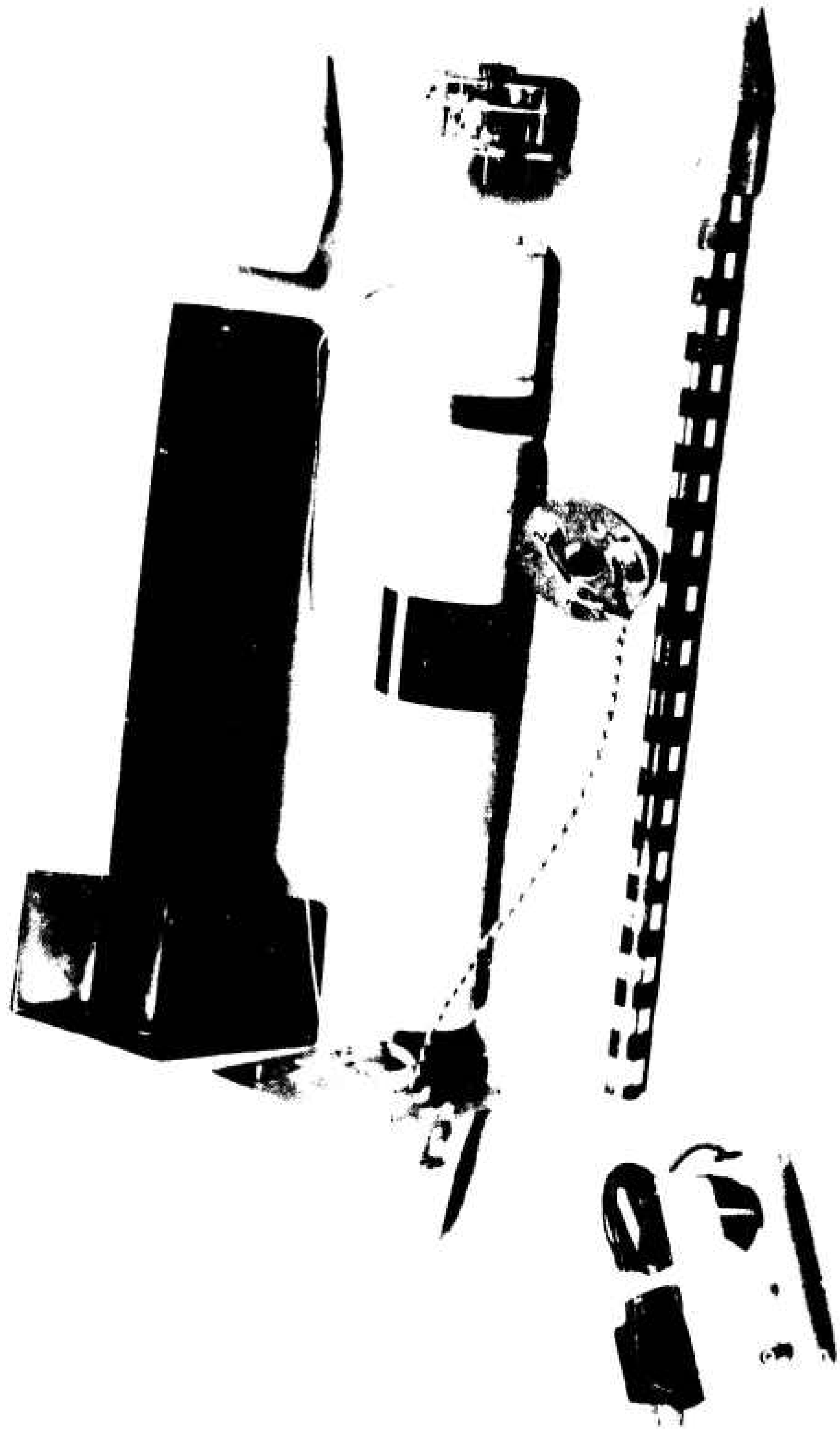

Figure 21. Penetrometer Assembly Photograph

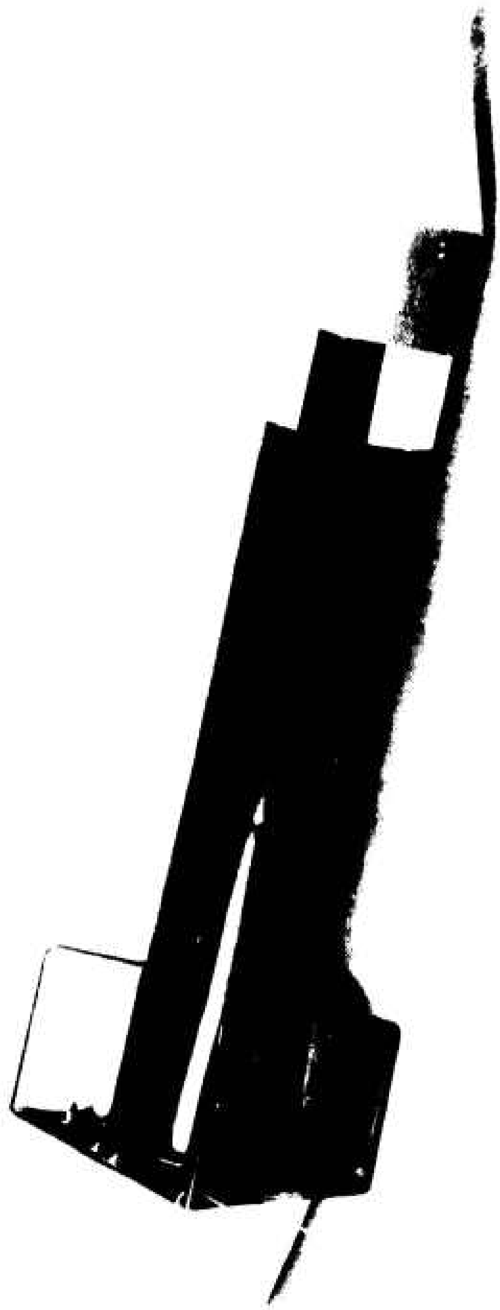

Figure 22. Assembled Penetrometer

occurred when the penetrometer hit directly on a large rock. This blunted the steel rod tip, requiring remachining. It also fractured the transmitter crystal and broke a diode. When a new crystal and diode were installed, the package operated normally.

Inspection of the unit after several drops showed that the battery deformed the connector plate at the rear of the package, causing mechanical damage to the coil forms and crystal can. To alleviate this a metal reinforcing plate was added.

The system is now believed to be mechanically sound and performing satisfactorily from an electronic standpoint. It should, perhaps, be pointed out that this system when viewed on a spectrum analyzer has quite a wide bandwidth. This results from the AM system not being linear since the driver is simply switched on and off at the 40-kHz subcarrier frequency. This is tantamount to pulse modulation at 40-kHz repetition rate which generates numerous side bands. Most of the energy, however, is in the carrier and first set of sidebands. These are all that are required by the receiver since there is no need to preserve square-wave fidelity to recover the data in the subcarrier. Because of the low power of the transmitter (0.4 W nominal), and the low-energy content of the wider sidebands, it is not anticipated that any problems will result from this method of modulation. The advantage of transmitter simplicity far outweighs the small loss of power in the unwanted sidebands.

The choice of frequencies leaves much to be desired since this is an active aircraft band. At some future time it would be desirable to obtain a less populated band.

Although the current system should be adequate to test the concept of the center rod penetrometer system, it is felt that further development should precede any field deployment of the system. Such development should be directed toward making a system compatible with existing aircraft radio installations. A wideband receiver is needed because data are transmitted at up to a 5000-Hz real-time data rate upon impact. Furthermore, it appears that a display system based on real-time analog data might be unwieldly and would probably require special crew training to accurately interpret the data. If the testing stage indicates that the center rod penetrometer would be a valuable system, a new concept should be developed. It should record the penetrometer data and then repeat it to the aircraft digitally at a slower data rate. This would permit

use of the normal aircraft receivers with an added readout device. If the amount of rod separation provides sufficient information for trafficability predictions, the proposed digital system (figure 10) would be little, if any, more complex than the analog. If additional parameters are required, complexity will increase, but the advantages of a digital approach warrant that consideration be given to such a follow-on unit.

4. FIELD TESTING AND ANALYSIS

Three prototype units were fabricated to evaluate the telemetry system under as wide a range of soil conditions as possible. On 15 October 1973, a series of 11 drops was made from a height of 600 feet to evaluate the system. A site was chosen on the McCormick Ranch playa where the soil is usually a hard silty clay with CBR greater than 20. The impact area was selected around a crater about 35 feet in diameter and 20 feet deep. The soils in the crater area have been loosened by explosives to very soft condition with a CBR of less than one.

Penetrometers impacting outside the crater area penetrated the hardest soils expected in operational use, while those impacting inside the crater area penetrated soils considerably softer than those an aircraft would be expected to land on. The wall of the crater slopes up to 30 degrees. Penetrometers that impacted on these walls performed satisfactorily and did not overturn.

All penetrators were dropped from a tethered weather balloon at a height of 600 feet. The penetrometers were aerodynamically stable at time of impact, although the impact velocity was considerably less than achieved in previous tests when the units were dropped from aircraft at 2000 feet AGL. The purpose of this test was to evaluate the telemetry system, so terminal velocities were not measured, and a detailed terradynamic analysis was not conducted. It should also be noted that the case and rod weights were considerably different than those used in earlier tests. These are tabulated in table 15.

Table 15

CHARACTERISTICS OF PROTOTYPE UNITS USED IN TESTING OF TELEMETRY SYSTEM

Total Unit Weight (lb)	Nose Configuration (L/D)	Center of Gravity (percent)	Rod Weight (lb)	Case Weight (lb)
5.5	2.0	73	2.8	2.7

Of the 11 drops, four impacted into very soft soils and seven impacted the hard soils. The telemetry system functioned well in each drop, producing usable returns. Several records were distorted because of voice interference by the FAA air route traffic control center (ARTCC) on the same frequency.

Five records were chosen as representative for detailed examination. These records are shown in figures 23 to 27 for drops 2, 3, 4, 8, and 11, respectively. Table 16 tabulates the time in milliseconds for each 0.5-inch interval when the rods separate from the case. Table 17 provides soil data on the impact area and measured separation data.

It should be noted that the transition point shown on the record is not the same for the sensor system when it is observing a shiny-to-dull interface on the rod as for the dull-to-shiny interface. However, for each complete cycle of shiny to dull and dull to shiny, the total times are the same. This is particularly evident on the records for drops 8 and 11. It should also be noted that separation measurements from telemetered data are accurate only to the nearest 0.5 inch, because this is the interval between the edges of the light and dark bands. This interval seems adequate for the present purposes but may have to be reduced for other requirements such as on very hard targets. The system in its present configuration is capable of measuring separations up to 15.5 inches. Greater separations cannot be recorded without increasing the rod length.

Separation velocities are tabulated in table 16 to provide insight into the behavior of the rod and case upon impact. The rod and case move together through the first part of impact. Then as the case is slowed by soil resistance, the rod begins to move faster until slowed by soil resistance. In drops 2, 3, and 4 where separation distances were small, measured maximum separation velocities up to 54 fps were measured. In drops 8 and 11, separation distances were large, and peak velocities were 49 fps and 66 fps, respectively. The soil in the impact area of drop 8 was considerably softer than where drop 11 impacted. The reason that separation velocities were higher in harder soils was the fact that the case comes to a stop faster in harder soils. In soft soils the case deceleration is much less than in hard soils. This means that case and rod velocities are closer to being the same, hence reduced separation velocities.

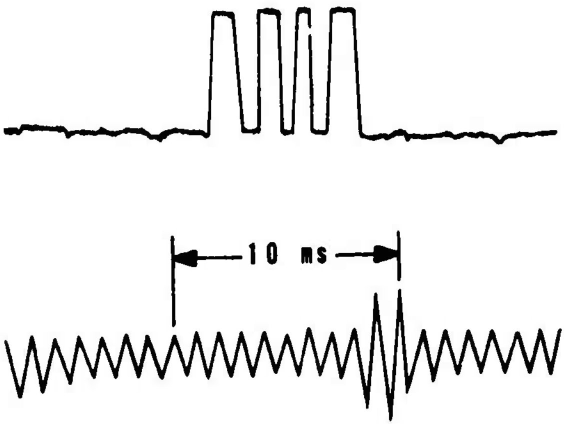

Figure 23. Drop 2 Time Record

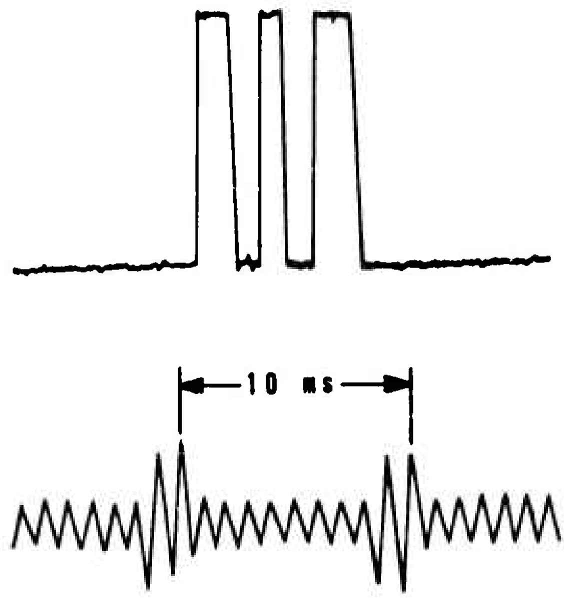

Figure 24. Drop 3 Time Record

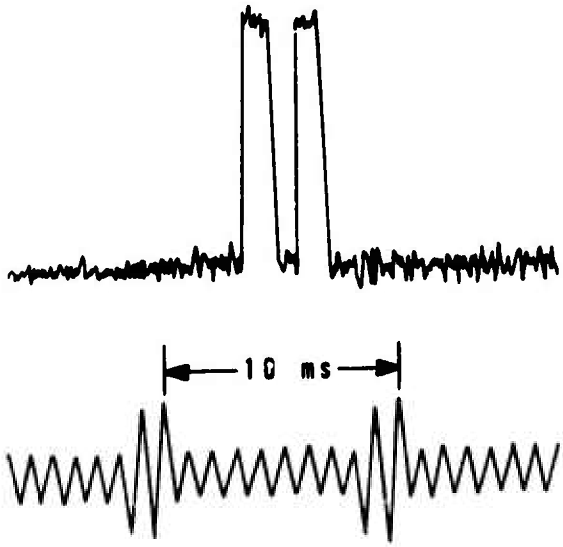

Figure 25. Drop 4 Time Record

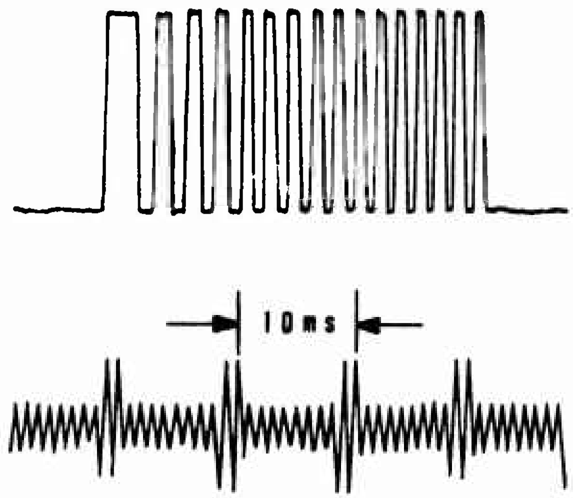

Figure 26. Drop 8 Time Record

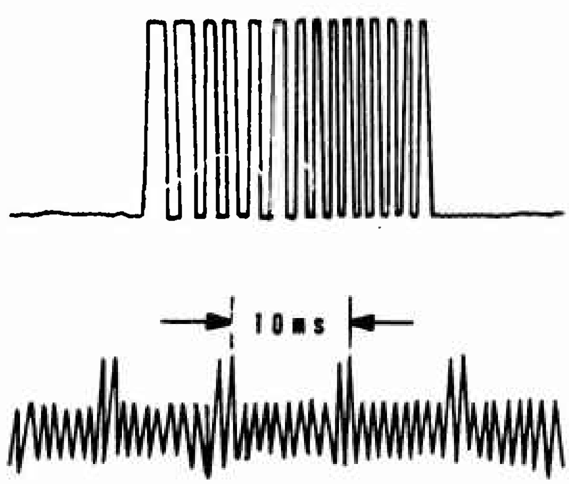

Figure 27. Drop 11 Time Record

Table 16

TIME AND SEPARATION VELOCITY DATA

Interval	Time (ms)	Cumulative Time (ms)	Velocity (fps)
Drop 2:			
0.5	1.36	1.36	---
1.0	0.89	2.25	37.04
1.5	0.83	3.08	---
2.0	0.76	3.84	54.41
2.5	0.71	4.55	---
3.0	0.83	5.38	54.11
0.29 ft = 3.5 in.	1.25	6.63	33.30
			*$\overline{X}$ = 44.21
			**S = 10.58
Drop 3:			
0.5	1.61	1.61	---
1.0	1.06	2.67	31.21
1.5	1.01	3.68	---
2.0	1.28	4.96	36.39
0.21 ft = 2.5 in.	1.88	6.84	22.16
			$\overline{X}$ = 29.92
			S = 7.20
Drop 4:			
0.5	1.25	1.25	---
1.0	0.92	2.17	38.4
0.13 ft = 1.5 in.	1.08	3.25	38.5
			$\overline{X}$ = 38.45
			S = 0.07
Drop 8:			
0.5	2.18	2.18	14.61
1.0	1.55	3.73	26.36
1.5	1.29	5.02	---
2.0	1.20	6.22	33.47
2.5	1.15	7.37	---
3.0	1.12	8.49	36.71

** $\overline{X}$ = Mean
** S = standard deviation

Table 16 (cont'd)

Interval	Time (ms)	Cumulative Time (ms)	Velocity (fps)
3.5	1.08	9.57	---
4.0	1.06	10.63	38.94
4.5	1.05	11.68	---
5.0	1.01	12.69	40.45
5.5	1.00	13.69	---
6.0	0.99	14.68	41.88
6.5	0.94	15.62	---
7.0	0.92	16.54	44.80
7.5	0.89	17.43	---
8.0	0.91	18.34	46.30
8.5	0.91	19.25	---
9.0	0.89	20.14	46.30
9.5	0.87	21.01	---
10.0	0.87	21.88	47.89
10.5	0.86	22.74	---
11.0	0.91	23.65	47.08
11.5	0.87	24.52	---
12.0	0.87	25.39	47.89
12.5	0.88	26.27	---
13.0	0.89	27.16	57.08
13.5	0.85	28.01	---
14.0	0.87	28.88	58.45
14.5	0.85	29.73	---
15.0	0.83	30.56	49.60
15.5	0.85	31.41	49.02
			$\overline{X}$ = 43.01
			S = 7.29

Drop 11:

Interval	Time (ms)	Cumulative Time (ms)	Velocity (fps)
0.5	1.59	1.59	21.47
1.0	1.10	2.69	33.32
1.5	0.90	3.59	---
2.0	0.98	4.57	44.33
2.5	0.81	5.38	---

Table 16 (cont'd)

Interval	Time (ms)	Cumulative Time (ms)	Velocity (fps)
3.0	0.80	6.18	51.76
3.5	0.74	6.92	---
4.0	0.75	7.67	55.93
4.5	0.73	8.40	---
5.0	0.74	9.14	57.47
5.5	0.72	9.86	---
6.0	0.70	10.56	58.69
6.5	0.65	11.21	---
7.0	0.70	11.91	61.73
7.5	0.67	12.58	---
8.0	0.68	13.26	61.73
8.5	0.63	13.89	---
9.0	0.65	14.54	65.10
9.5	0.62	15.16	---
10.0	0.65	15.81	65.62
10.5	0.63	16.44	---
11.0	0.62	17.06	66.67
11.5	0.64	17.70	---
12.0	0.66	18.36	64.00
12.5	0.65	19.01	---
13.0	0.66	19.67	63.61
13.5	0.67	20.34	---
14.0	0.66	21.00	62.66
14.5	0.66	21.66	---
15.0	0.67	22.33	62.66
15.5	0.67	23.00	62.19
			$\overline{X}$ = 55.44
			S = 9.30

Table 17

FIELD SOIL MEASUREMENTS

	Depth (in)	ACP	DCP	Avg	
Drop 2:					
	3	9.0	---	---	
	6	11.0	6	8.0	Rod separation = 3.5 inches
	9	11.5	---	---	Case penetration = 5.7 inches
	12	12.8	18.3	15.3	Rod penetration = 9.2 inches
	18	19.3	19.7	19.5	
Drop 3:					
	3	6.3	---	---	
	6	8.3	8.3	7.8	Rod separation = 3.0 inches
	9	6.0	---	---	Case penetration = 5.7 inches
	12	5.0	23.0	14.3	Rod penetration = 8.7 inches
	18	17.0	14.3	15.7	
Drop 3					
	3	16.0	---	---	
	6	7.0	11.2	11.4	Rod separation = 2 inches
	9	7.0	---	---	Case penetration = 6.2 inches
	12	7.0	35.8	21.4	Rod penetration = 8.2 inches
	18	R	33.0	33.0	
Drop 8					
	3	0.0	---	---	
	6	1.0	0.0	0.25	Rod separation = 45.5 inches
	12	0.1	0.0	0.05	Case penetration = 18.2 inches
	18	0.3	0.3	0.3	Rod penetration = 63.7 inches
	24	0.3	0.3	0.3	
	30	---	0.3	0.3	
	36	---	0.3	0.3	
	42	---	1.0	1.0	
	48	---	1.3	1.3	

Table 17 (cont'd)

	Depth (in)	ACP	DCP	Avg	
Drop 11:					
	3	1.0	---	---	
	6	1.0	0.7	0.9	
	12	1.2	1.0	1.1	Rod separation = 35.5 inches
	18	1.7	0.7	1.7	Case penetration = 16.2 inches
	24	3.0	1.3	2.2	Rod penetration = 51.7 inches
	30	---	1.0	1.0	
	36	---	2.0	2.0	
	42	---	3.0	3.0	
	48	---	4.3	4.3	

Attempts were made to compare static data from the telemetered penetrometer with data collected from earlier tests. Because soil conditions were not comparable and case and rod weights were different, these attempts were unsuccessful. For completeness, a plot for the telemetered penetrometer similar to those in figure 7 to 9 is shown in figure 28. Results of 11 tests are plotted on this figure. The large data scatter is believed to be caused by variations in impact velocity and inhomgeneities in the soil ejecta around the crater. Clods of soil in the ejecta can lead to serious ACP-DCP measurement errors.

In summary, the telemetry system performed successfully and reliably. Before further testing can be conducted to fully develop penetrometer-to-aircraft performance relationships, minor changes in the rod and transmitter design must be made These changes are to increase rod weight or reduce weight and to change the transmitter frequency.

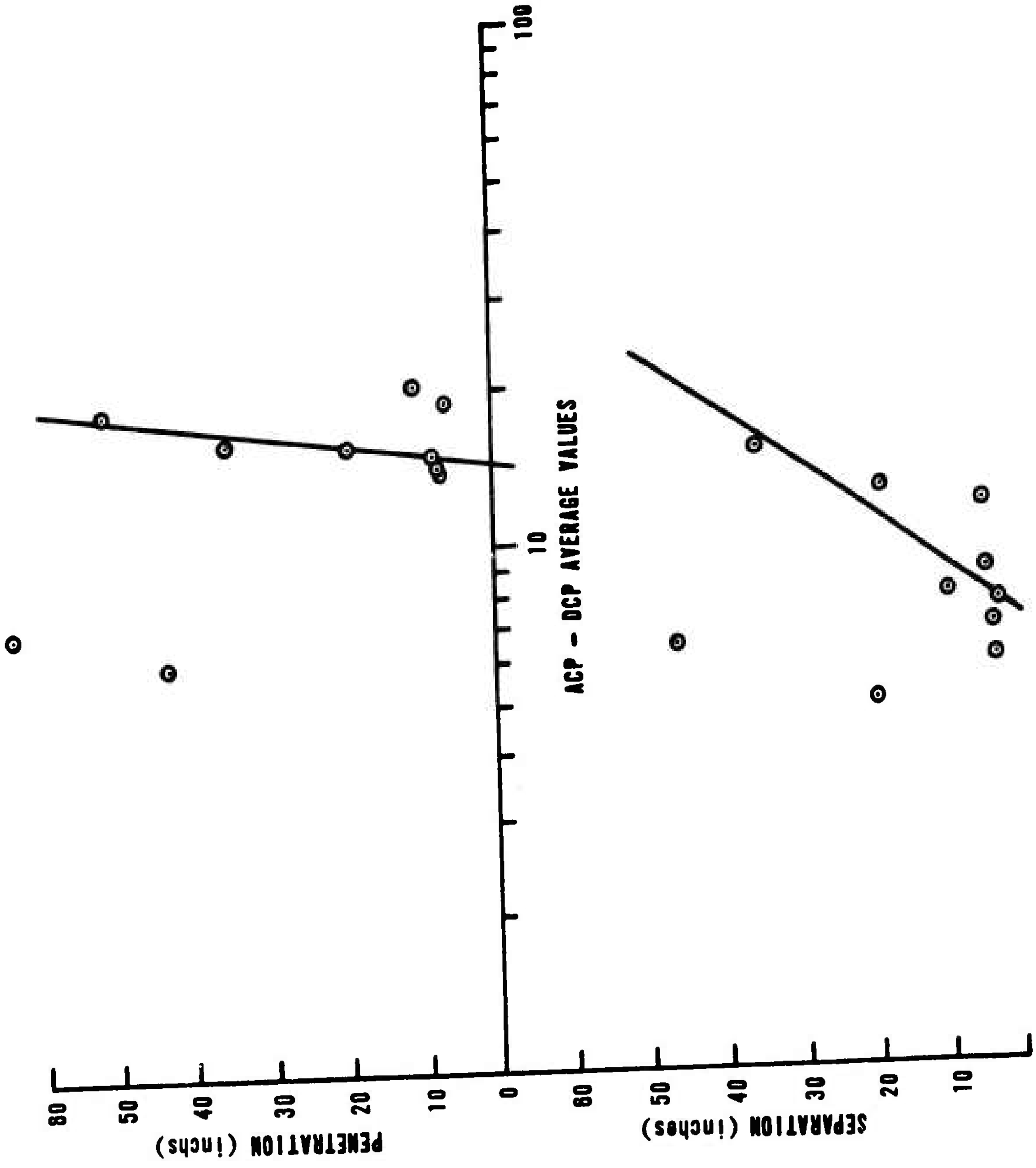

Figure 28. Penetration and Separation versus Average ACP-DCP Values, Penetrometer with Telemetry

SECTION IV

SUMMARY AND CONCLUSIONS

During this study the feasibility evaluation and the conceptual development of an inexpensive penetrometer to measure aircraft trafficability on soil runways was completed. Examination of trajectory and implant data from 31 tests with five different units has shown that the concept of using the penetration and separation of a heavy small-diameter rod from a light, large-diameter case on impact with the soil can provide reliable information on the trafficability of a potential landing site.

This conclusion is based on a number of findings and previously known facts and is based on the premise that the ACP and DCP are reasonably good indicators of aircraft trafficability. Further conclusions are:

a. For at least two cases, a predictable correspondence between the total penetration of the rod and the separation distance between case and rod had been shown to exist.

b. Based on estimated cost of components, the penetrometer could be mass produced (10,000 units) for less than $25 each.

c. Aerodynamic and terradynamic performance of all units was within the ranges anticipated. There were no structural failures. Only one unit failed to separate.

d. An inexpensive reliable telemetry system utilizing a photo-transistor sensor and an FM/AM transmitter is feasible and has been constructed and tested.

Summarizing the major findings of this investigation, the following are most important.

a. Best overall performance could be expected from a unit with a 7.0 to 7.5 pound total weight with the rod 1.5 to 2.0 times the case weight and a nose L/D of 2.0 This combination provides the greatest impact velocity, the most predictable performance, the highest angle of implant, and the desired penetration.

b. The practice of obtaining ACP and DCP readings at three locations near the penetrometer implant provides extremely valuable statistical data

necessary for detailed analyses. Soil moisture content and density will be necessary to evaluate time-decceleration and time-separation data.

c. Although the wide range in hardness of the soils tested provided valuable limiting criteria, future testing should be directed toward soil closer to the hardness where trafficability problems may be encountered (i.e., ACP or DCP of 6 to 25 per 6 inches).

d. A study of laboratory tests on clays, silts, and fine sands is required to develop a model to predict trafficability as it varies with the rate of loading. With this knowledge, precise relationships between trafficability and penetrability can be developed and modified as required by findings from full scale field tests from programs such as the Advanced Medium Short Takeoff and Landing (STOL) Transport (AMST).

e. The telemetry system developed provides a highly reliable method to obtain a time history of each event.

The results presented in this report are based on a limited number of tests under a broad range of conditions. The best analysis can only be qualitative. To attempt to quantify would not be practical. The data demonstrates that further development of the concept will probably be sucessful. The next objective should be the detailed testing of a telemetry equipped unit on hard, medium, and soft soils.

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